# Future sensors - planetary prospective

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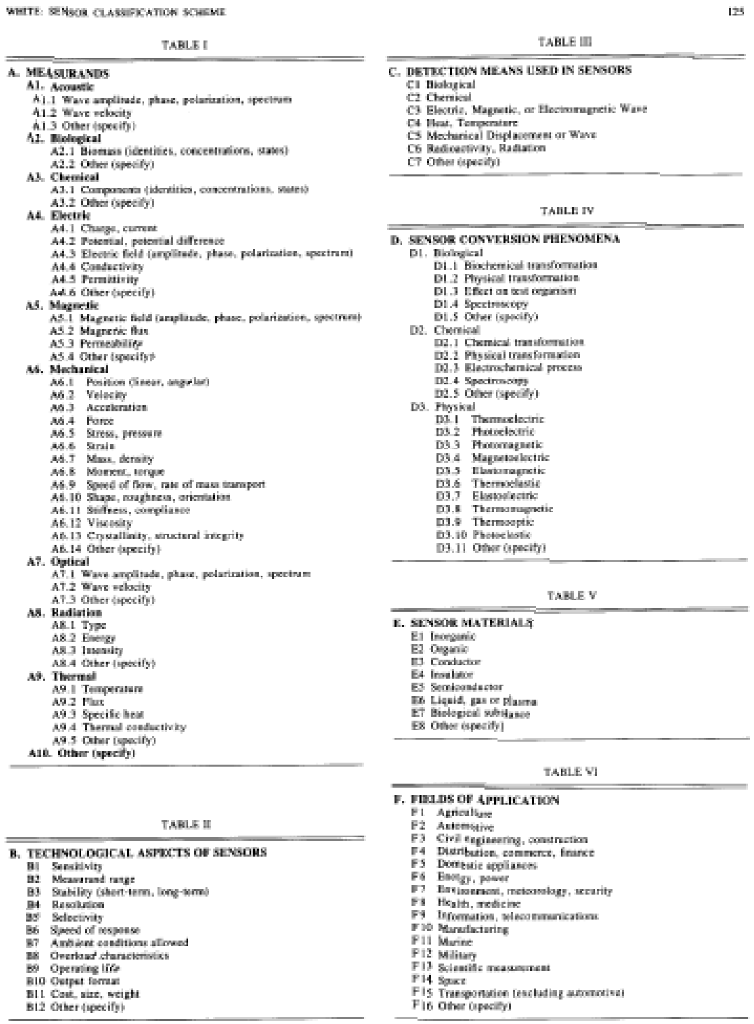
**National Workshop on Future Sensing Systems**

Lake Tahoe, California, August 26-28, 2002.

# NDEAA Technologies at JPL

- **Sensors**
  - USDC as a platform for bit integrated sensors
  - In-process and in-service monitoring (Surface Acoustic Wave (SAW) and Bulk Acoustic Wave (BAW) sensors)
- **NDE**
  - Materials properties and flaws characterization using leaky Lamb waves (LLW) and polar backscattering
- **Ultrasonic Medical Diagnostics and Treatment**
  - High power ultrasound (FMPUL): blood clot lysing, spine trauma and cancer treatment
  - Acoustic Microscopy Endoscope (200MHz)
- **Advanced Actuators**
  - Ultrasonic/Sonic Driller/Corer (USDC) for planetary exploration
  - Ultrasonic motors (USM), Surface Acoustic Wave (SAW) motors and Piezopump
  - Artificial muscles using electroactive polymers
- **Applications: Radiation sources, Robotics, etc.**
  - Ferrosource for multiple radiation types
  - Noninvasive geophysical probing system (NGPS)
  - Multifunction Automated Crawling System (MACS)
  - Adjustable gossamer and membrane structures
  - MEchanical MIrroring using Controlled stiffness and Actuators (MEMICA) as Haptic interfaces

# Many sensors have already been developed so: what else is needed?



WHITE: SENSOR CLASSIFICATION SCHEME 125

TABLE I

- A. **MEASURANDS**
  - A1. **Acoustic**
    - A1.1 Wave amplitude, phase, polarization, spectrum
    - A1.2 Wave velocity
    - A1.3 Other (specify)
  - A2. **Biological**
    - A2.1 Biomass (identities, concentrations, states)
    - A2.2 Other (specify)
  - A3. **Chemical**
    - A3.1 Components (identities, concentrations, states)
    - A3.2 Other (specify)
  - A4. **Electric**
    - A4.1 Charge, current
    - A4.2 Potential, potential difference
    - A4.3 Electric field (amplitude, phase, polarization, spectrum)
    - A4.4 Conductivity
    - A4.5 Permittivity
    - A4.6 Other (specify)
  - A5. **Magnetic**
    - A5.1 Magnetic field (amplitude, phase, polarization, spectrum)
    - A5.2 Magnetic flux
    - A5.3 Permeability
    - A5.4 Other (specify)
  - A6. **Mechanical**
    - A6.1 Position (linear, angular)
    - A6.2 Velocity
    - A6.3 Acceleration
    - A6.4 Force
    - A6.5 Stress, pressure
    - A6.6 Strain
    - A6.7 Mass, density
    - A6.8 Moment, torque
    - A6.9 Speed of flow, rate of mass transport
    - A6.10 Shape, roughness, orientation
    - A6.11 Stiffness, compliance
    - A6.12 Viscosity
    - A6.13 Crystallinity, structural integrity
    - A6.14 Other (specify)
  - A7. **Optical**
    - A7.1 Wave amplitude, phase, polarization, spectrum
    - A7.2 Wave velocity
    - A7.3 Other (specify)
  - A8. **Radiation**
    - A8.1 Type
    - A8.2 Energy
    - A8.3 Intensity
    - A8.4 Other (specify)
  - A9. **Thermal**
    - A9.1 Temperature
    - A9.2 Flux
    - A9.3 Specific heat
    - A9.4 Thermal conductivity
    - A9.5 Other (specify)
  - A10. **Other (specify)**

TABLE II

- B. **TECHNOLOGICAL ASPECTS OF SENSORS**
  - B1 Sensitivity
  - B2 Measurand range
  - B3 Stability (short-term, long-term)
  - B4 Resolution
  - B5 Selectivity
  - B6 Speed of response
  - B7 Ambient conditions allowed
  - B8 Overload characteristics
  - B9 Operating life
  - B10 Output format
  - B11 Cost, size, weight
  - B12 Other (specify)

TABLE III

- C. **DETECTION MEANS USED IN SENSORS**
  - C1 Biological
  - C2 Chemical
  - C3 Electric, Magnetic, or Electromagnetic Wave
  - C4 Heat, Temperature
  - C5 Mechanical Displacement or Wave
  - C6 Radioactivity, Radiation
  - C7 Other (specify)

TABLE IV

- D. **SENSOR CONVERSION PHENOMENA**
  - D1. Biological
    - D1.1 Biochemical transformation
    - D1.2 Physical transformation
    - D1.3 Effect on test organism
    - D1.4 Spectroscopy
    - D1.5 Other (specify)
  - D2. Chemical
    - D2.1 Chemical transformation
    - D2.2 Physical transformation
    - D2.3 Electrochemical process
    - D2.4 Spectroscopy
    - D2.5 Other (specify)
  - D3. Physical
    - D3.1 Thermoelectric
    - D3.2 Photoelectric
    - D3.3 Photomagnetic
    - D3.4 Magnetoelectric
    - D3.5 Elastomagnetic
    - D3.6 Thermoelastic
    - D3.7 Elastoelectric
    - D3.8 Thermomagnetic
    - D3.9 Thermooptic
    - D3.10 Photoelastic
    - D3.11 Other (specify)

TABLE V

- E. **SENSOR MATERIALS**
  - E1 Inorganic
  - E2 Organic
  - E3 Conductor
  - E4 Insulator
  - E5 Semiconductor
  - E6 Liquid, gas or plasma
  - E7 Biological substance
  - E8 Other (specify)

TABLE VI

- F. **FIELDS OF APPLICATION**
  - F1 Agriculture
  - F2 Automotive
  - F3 Civil engineering, construction
  - F4 Distribution, commerce, finance
  - F5 Domestic appliances
  - F6 Energy, power
  - F7 Environment, meteorology, security
  - F8 Health, medicine
  - F9 Information, telecommunications
  - F10 Manufacturing
  - F11 Marine
  - F12 Military
  - F13 Scientific measurement
  - F14 Space
  - F15 Transportation (excluding automotive)
  - F16 Other (specify)

REF: White, R. M., "A sensor classification scheme", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. UFFC-34, No. 2, March 1987, pp. 124-126

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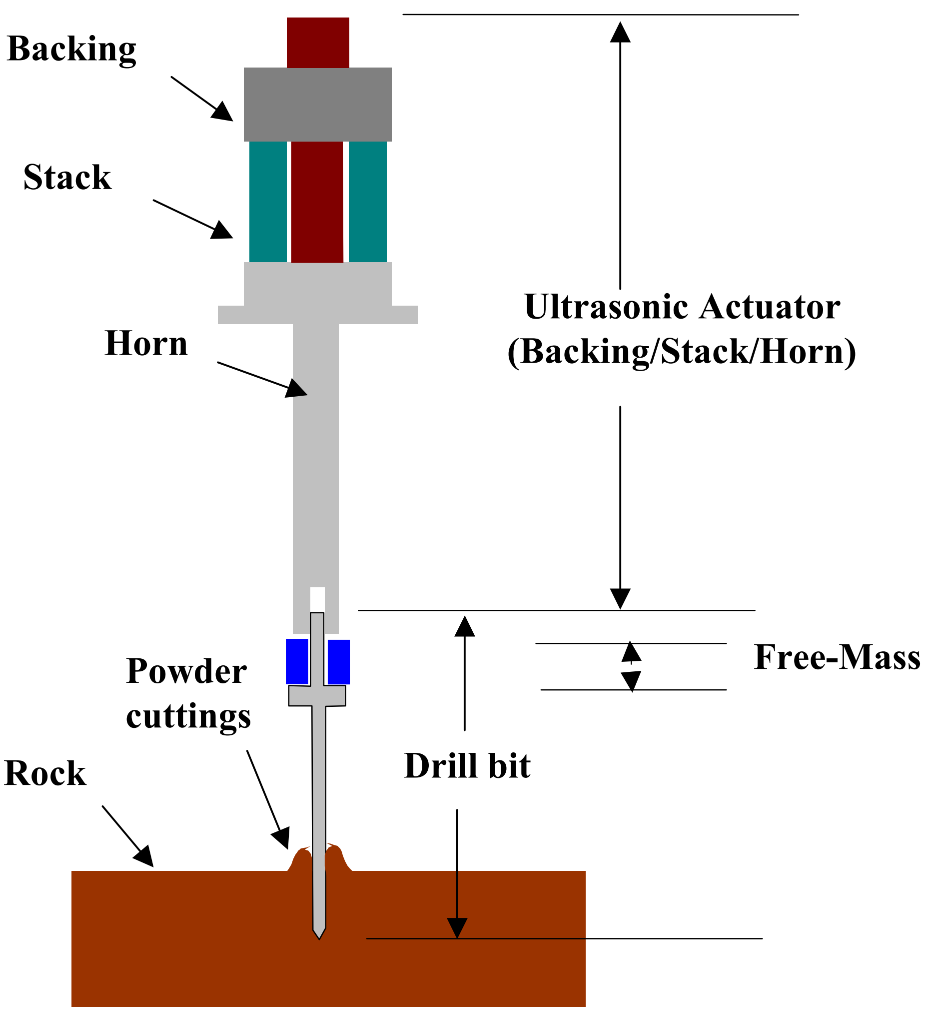
# Research areas with special needs for sensor

- Planetary in-situ sample analysis
  - Ultrasonic drill (high temp, sensing, probing, gopher)
  - Lab-on-chip
- Gossamer and adjustable shape membranes
- Aerospace structures
- Biologically-inspired robotics
- Electroactive Polymers (EAP)
- Haptic interfaces

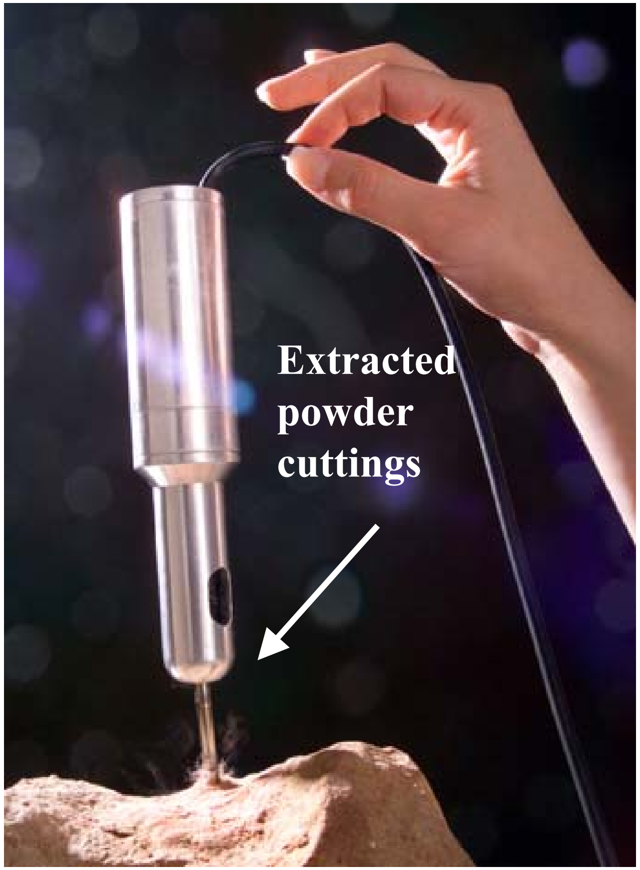
# Sensors categories that are considered

- Imbedded sensors (localized or distributed)
- Surface coated (e.g., bruising paint, brittle coating)
- Attached sensors (e.g., cracking fuse, strain gage, fiber optics)
- Adjacent/inductive (e.g., eddy current, ultrasonic, magnetic, visual)
- Remote sensors (e.g., visual, sonic, infrared)

# Ultrasonic/Sonic Driller/Corer (USDC)



2000 R&D 100 award



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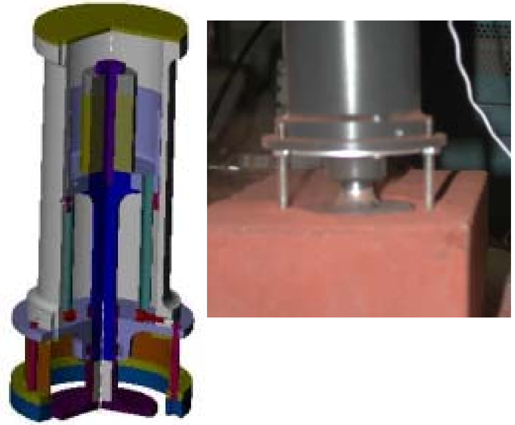
# Ultrasonic/Sonic Drill and Corer (USDC)



Ultrasonic rock abrasion tool

Ultrasonic Gophers for deep drilling

USDC is a drill that uses low axial force and does not require bit sharpening

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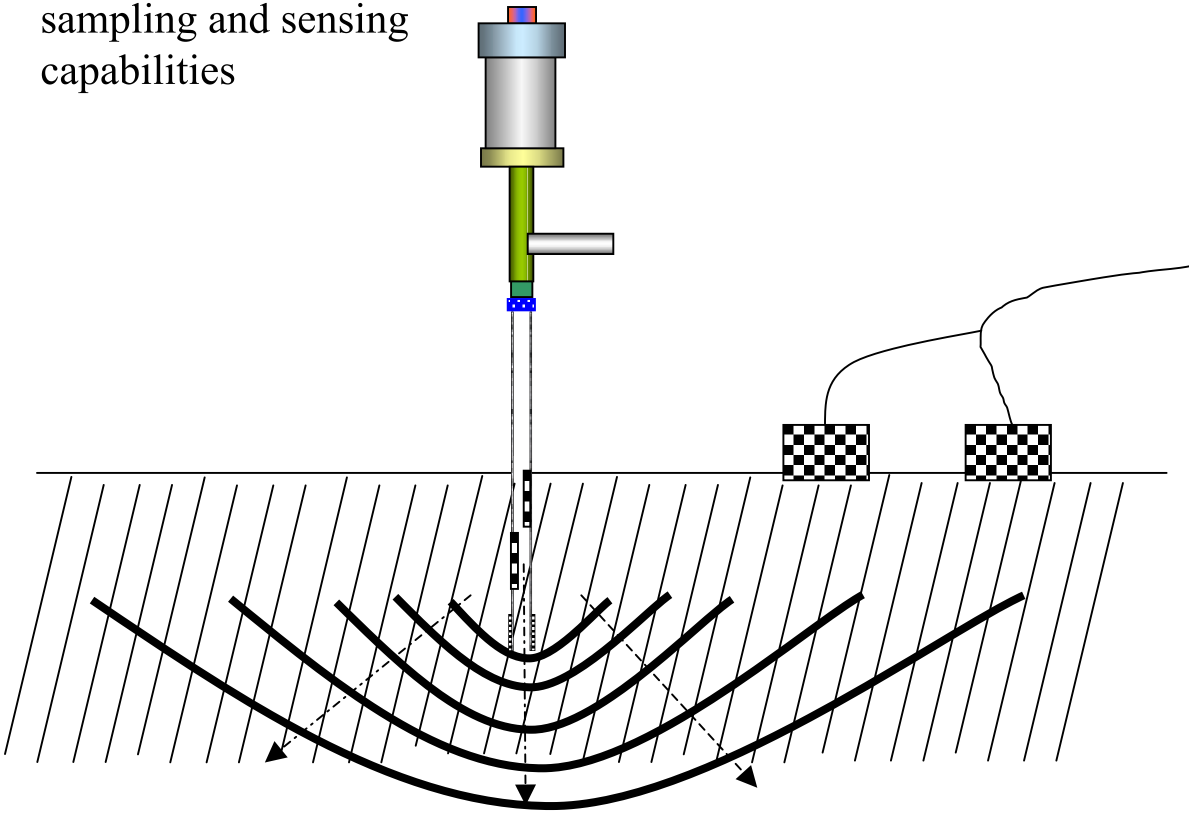
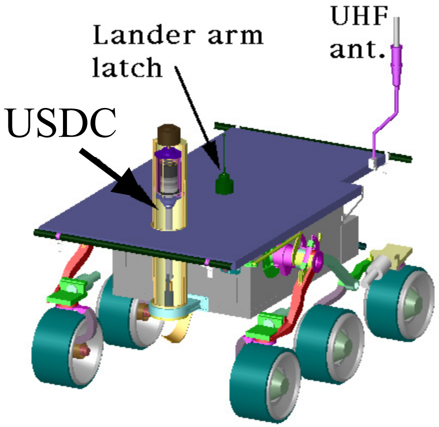
# Smart USDC

Seeking to make a smart USDC with probing/ sampling and sensing capabilities





Part of the proposed Scout mission to Mars (To e launched in 2007)

# Probing, sampling and sensing

The USDC is being studied as a probing device that can sample cores, powdered cuttings and gases as well as operate as a platform for sensors

Noninvasive probing -The reflection and transmission of imparted elastic waves (bulk and surface) were measured to establish means of rocks characterization. Also, the effect of loading the actuator by the sample were monitored by measuring the change in impedance and resonance frequency.

Sampling techniques – Methods of operating the bit as an all-in-one unit for extraction of cored rocks (including basalt) with maximum integrity were developed. A device for the acquisition of powdered cutting and gases is being produced by Cybersonics and is expected to be delivered soon.

Integrated sensors

- An integrated thermocouple showed great potential in determining the hardness of drilled rocks using the heating rate and maximum temperature rise. Assuming relatively similar heat transfer to rocks, this should provide an effective sensing technique. It would also help protecting cored samples from thermal damage.
- We demonstrated the integration of an optical-fiber into a bit. Currently, we are working with two fiberoptic companies to determine what is feasible using integrated optical-fibers. These companies are: Ocean Optics and Research International.

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# Sensor requirements

The characteristics of the required sensors are

- Detect life, biological markers and water
- Support mineralogy, chemical, physical properties, crystallography and/or geological content analysis
- Small cross-section and low mass
- Driven by minimal power
- Operational at high (Venus: 460°C) and low (Titan ~ - 200°C) temperature
- Durable to harsh environment and cyclic impacts

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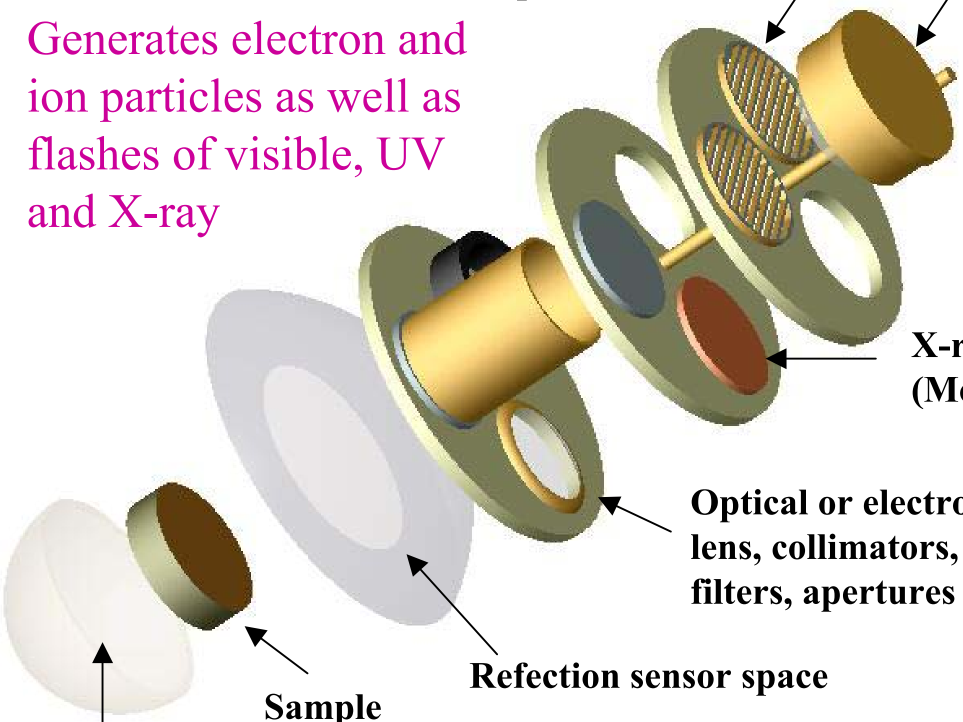
# Ferrosource and fixtures for emission of multiple radiation types

Generates electron and ion particles as well as flashes of visible, UV and X-ray



**Positive/Negative grids or aperture**

**Ferrosource**

**X-ray targets (Mo, Cu metal)**

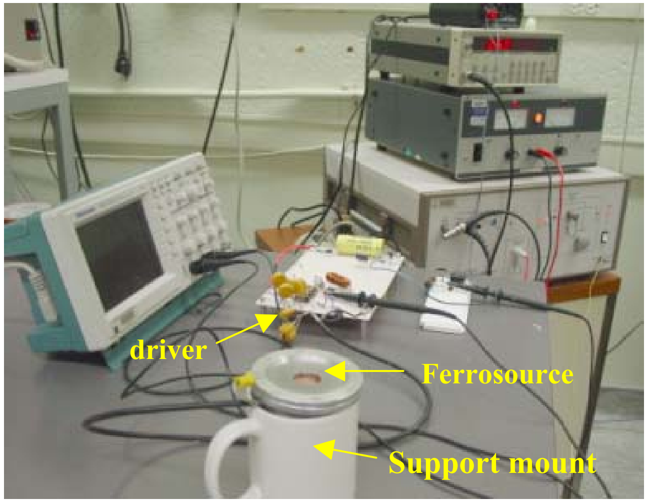
**Optical or electrostatic lens, collimators, filters, apertures**

**Refection sensor space**

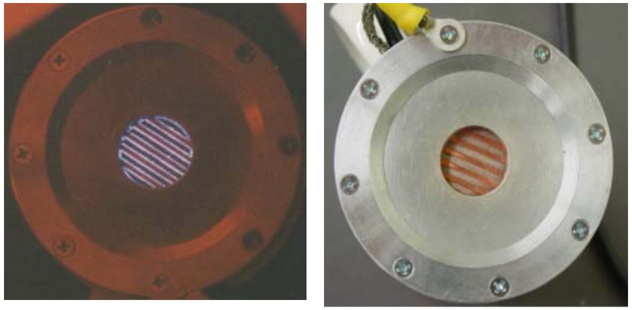
**Sample**

**Transmission sensor space**

**Requires:** miniature, multi-functional sensors



**Ferrosource**



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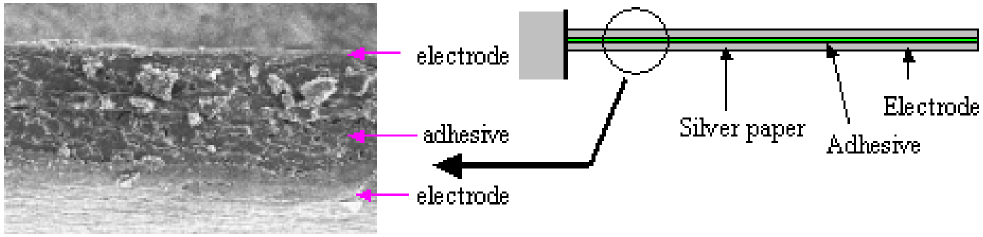
# Electronic EAP

Electric field or coulomb forces driven actuators

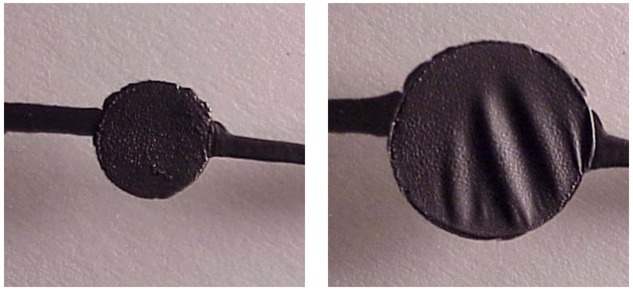


**Paper EAP**

**[J. Kim, Inha University, Korea]**

**Ferroelectric**

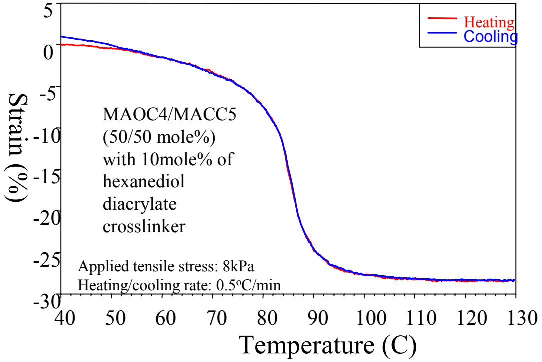
**[Q. Zhang, Penn State U.]**



**Voltage Off** **Voltage On**

**Dielectric EAP**

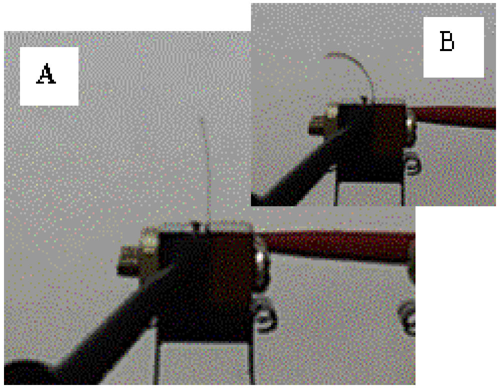
**[R. Kornbluh, et al., SRI International]**



**Liquid crystals**

(Piezoelectric and thermo-mechanic)

**[B. R. Ratna, NRL]**



**Graft Elastomer**

**[J. Su, NASA LaRC]**

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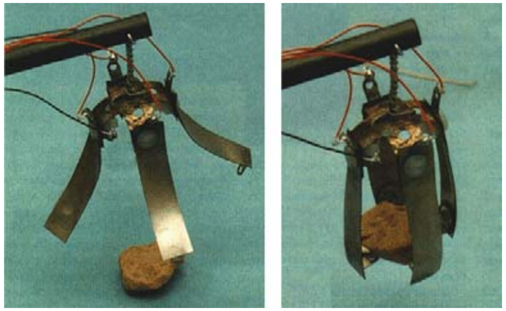
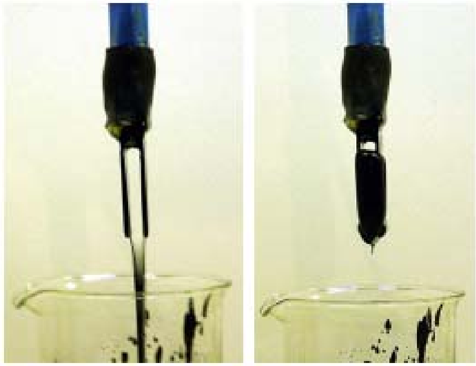
# Ionic EAP

## Turning chemistry to actuation



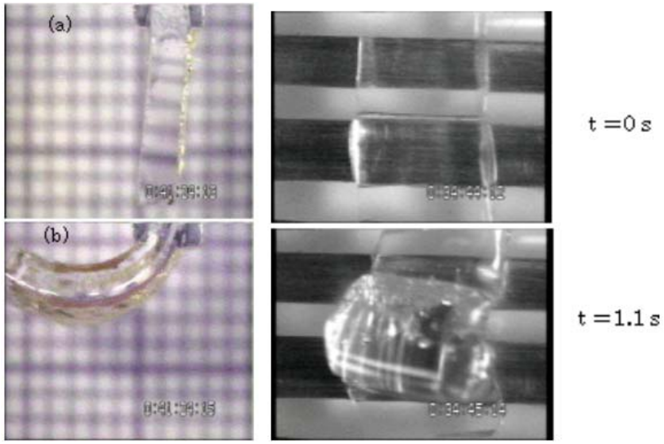
**IPMC**

**[JPL using ONRI, Japan & UNM materials]**



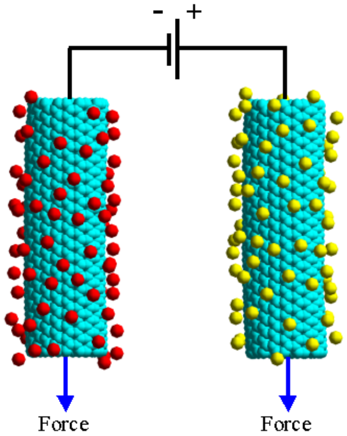
**ElectroRheological Fluids (ERF)**

**[ER Fluids Developments Ltd]**



**Ionic Gel**

**[T. Hirai, Shinshu University, Japan]**



**Carbon-Nanotubes**

**[R. Baughman et al, Honeywell, et al]**

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# Applications

## Underway or under consideration

- **Mechanisms**
  - Lenses with controlled configuration
  - Mechanical lock
  - Noise reduction
  - Flight control surfaces/Jet flow control
  - Anti G-suit
- **Robotics, Toys and Animatronics**
  - Biologically-inspired robots
  - Toys and Animatronics
- **Human-Machine Interfaces**
  - Haptic interfaces
  - Tactile interfaces
  - Orientation indicator
  - Smart flight/diving suits
  - Artificial nose
  - Active Braille display
- **Planetary Applications**
  - Sensor cleaner/wiper
  - Shape control of gossamer structures
- **Medical Applications**
  - EAP for biological muscle augmentation or replacement
  - Miniature in-vivo EAP robots for Diagnostics and microsurgery
  - Catheter steering mechanism
  - Tissues growth engineering
  - Interfacing neuron to electronic devices Using EAP
  - Active bandage
- **Liquid and Gases Flow Control**
- **Controlled Weaving**
  - Garment and clothing
- **MEMS**
- **EM Polymer Sensors &Transducers**

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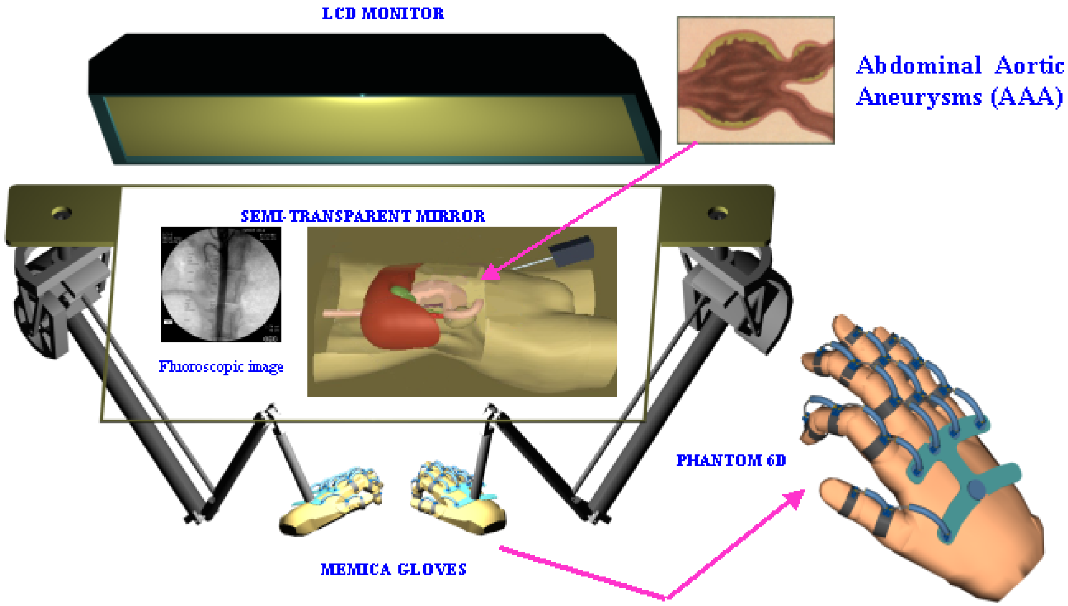
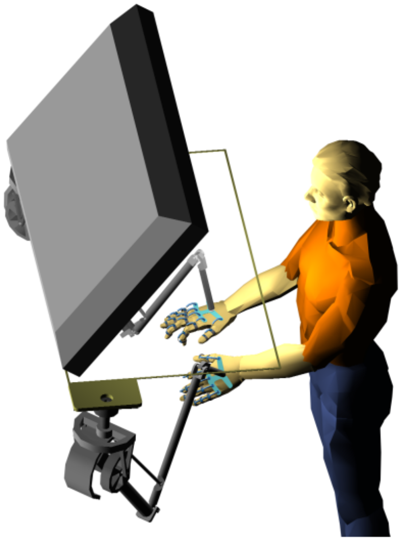
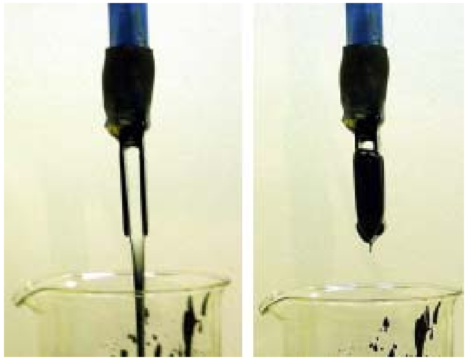
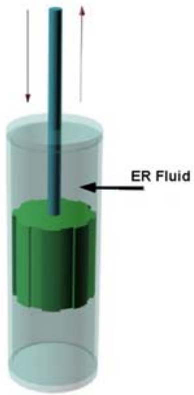
# Haptic Interfacing – MEMICA System

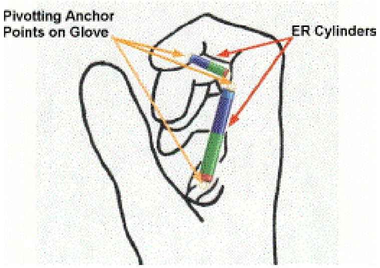
## (MEchanical MIrroring using Controlled stiffness and Actuators)











Electro-Rheological Fluid at reference (left) and activated states (right). [Smart Technology Group, UK]

# Emerging biomimetic technologies

- Biologically inspired robots
- Nano-bio technologies
- Scalable and/or reconfigurable robots
- Artificial muscle actuated mechanisms

Grand challenge for EAP
Arm wrestling with human

# Required sensors

- Flexible
- Light weight
- Imbeddable
- Miniature distributable
- Easy to multiplex
- Easy to connect and integrate
- Self powered or utilize the equivalence of biologically system (use resources from the adjacent environment)

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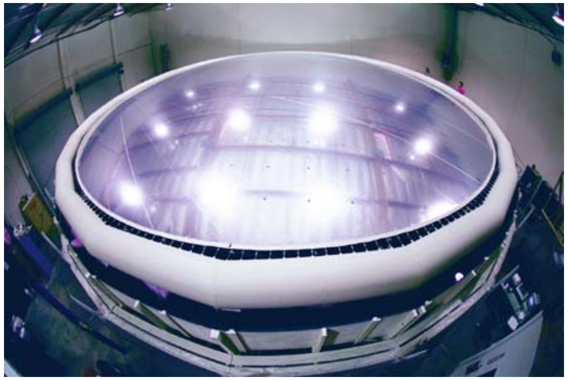
# Enabling Fabrication, Deployment, and Control of Precision Gossamer Apertures (PGA) Through Adaptive Gore/Seam Architectures

## The problem

- Large PGAs have been made in the past by seaming together smaller segments or *gores*
- This is likely to continue for the near-term.

Echo Satellite
NASA Langley Research Center 8/5/1965 Image # EL-2000-00441



“Active Seams” – PI: C. Jenkins, SDSMT
Team: Y. Bar-Cohen, M. Salama and A. Vinogradov

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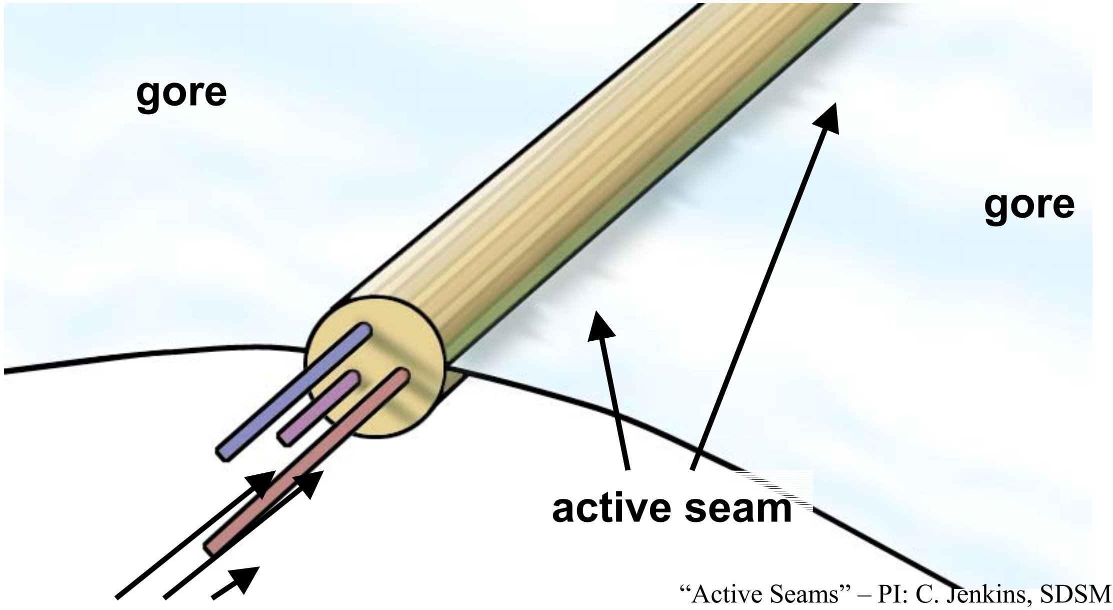
# The solution

Shifting the paradigm to: “let’s take advantage of the opportunities that seams present!”



“Active Seams” – PI: C. Jenkins, SDSMT
Team: Y. Bar-Cohen, M. Salama and A. Vinogradov

- Communication filaments
- Power filaments
- Misc. active elements
- Sensors

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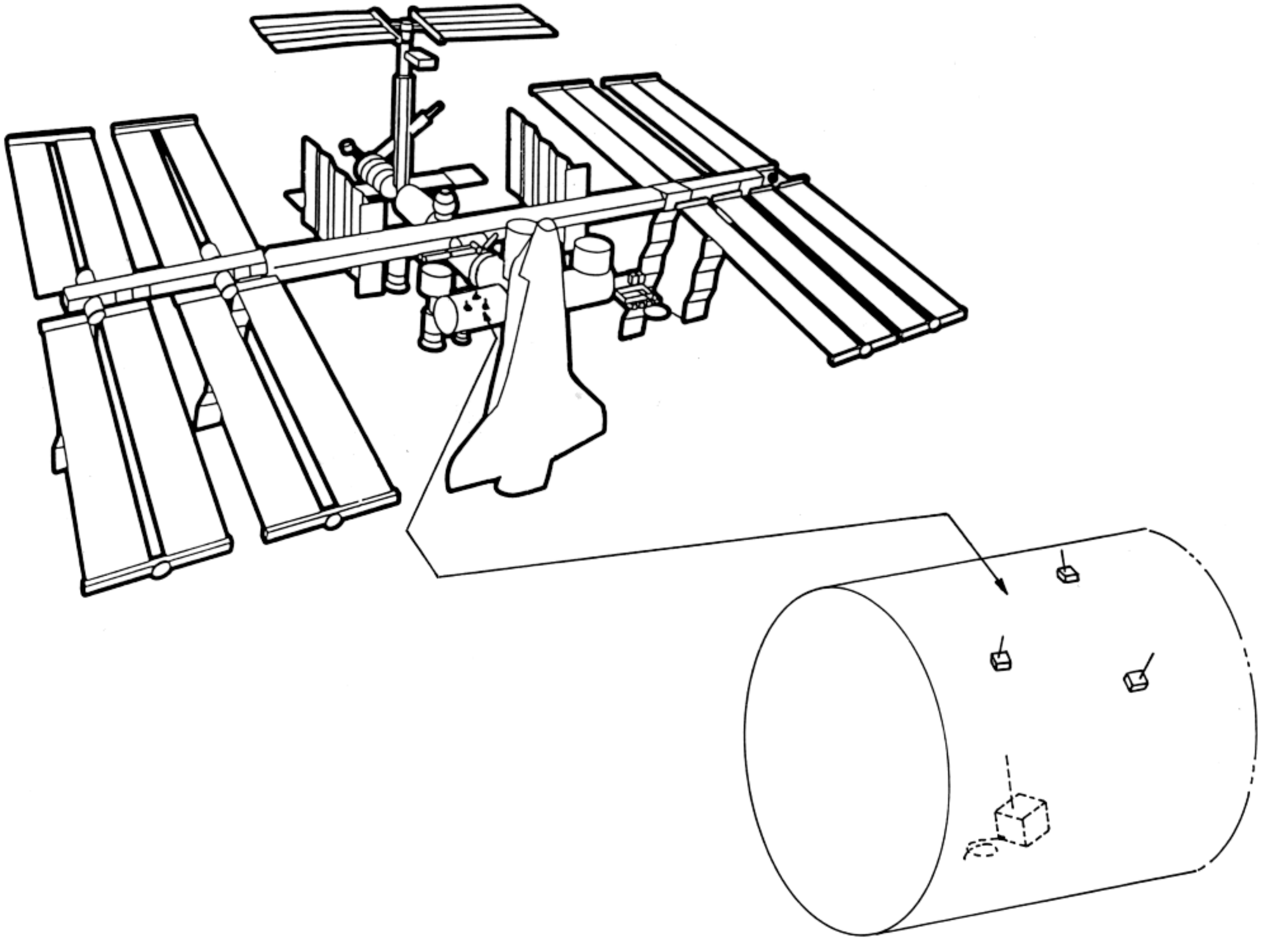
# Tele-stick-on sensor system



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# Sensors for ultrasonics and acoustic emission NDE

We need the equivalence of the ear in a miniature sensor/instrument

Namely: acquire the phase and amplitude of signals over a very broadband with minimal roll-off on both ends and very high signal to noise and fidelity.

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# Summary

**There is a need for sensors that can:**

operate at

- Harsh environments and extreme conditions (physical, mechanical, chemical or biological)
- Areas that are beyond reach

perform

- Test large-areas at high-speeds
- Real-time operation from cradle to retirement
- Broadband with phase and amplitude spectral data
- Accurately acquire nonlinear data
- Distributed sensing
- Multifunction

be

- Reliable and robust
- Scalable (MEMS, Miniaturizable to nano levels, etc.)
- Wireless
- Self powered or utilize the equivalence of biologic system (e.g., use resources from the adjacent environment, etc.)

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