Microbots for the Exploration of the Surface and Caves of the Bodies of the Solar System

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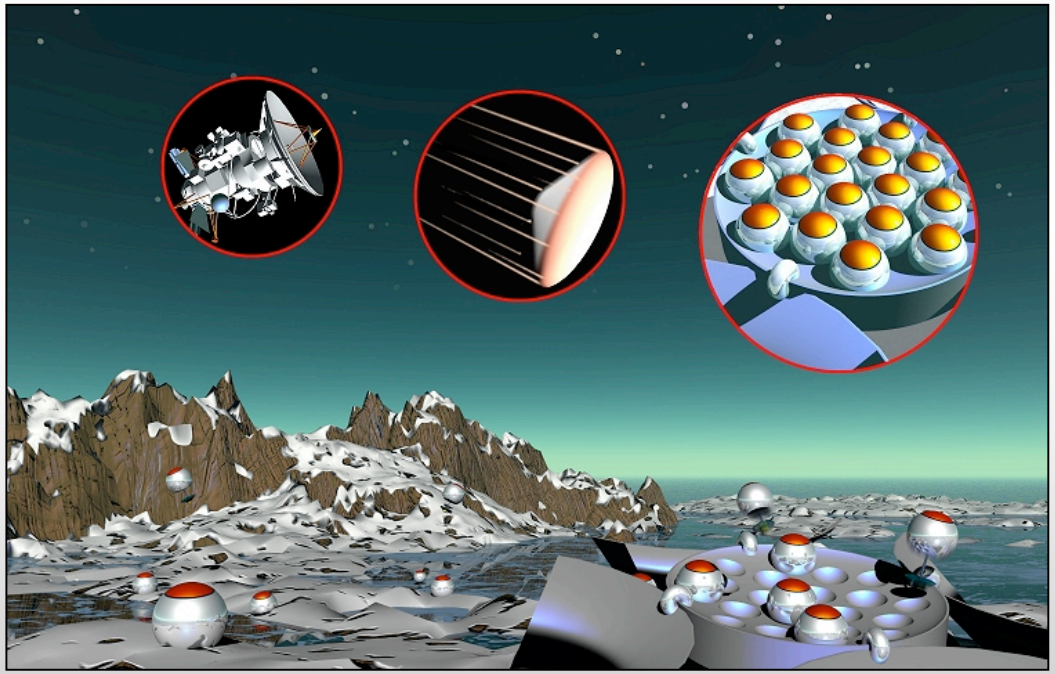
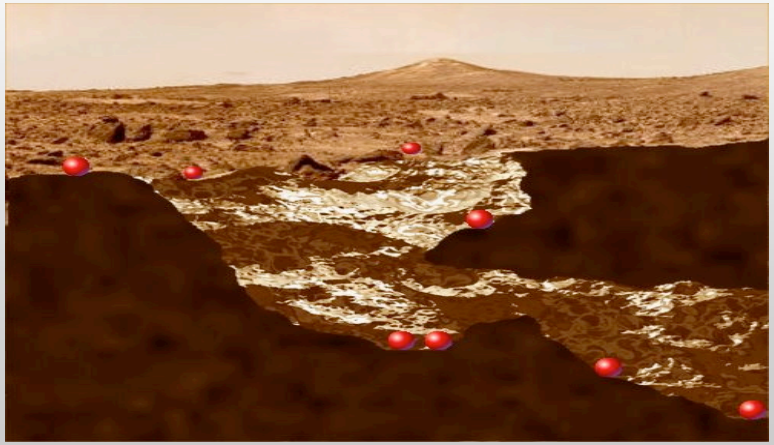
Massachusetts Institute of Technology

The Mission Concept

Deploy thousands of small mobile microbots over a planet's surface and subsurface

- Allows the scientific study of very large-area surface areas in extremely difficult terrains
- Allows the scientific study caves other subsurface domains

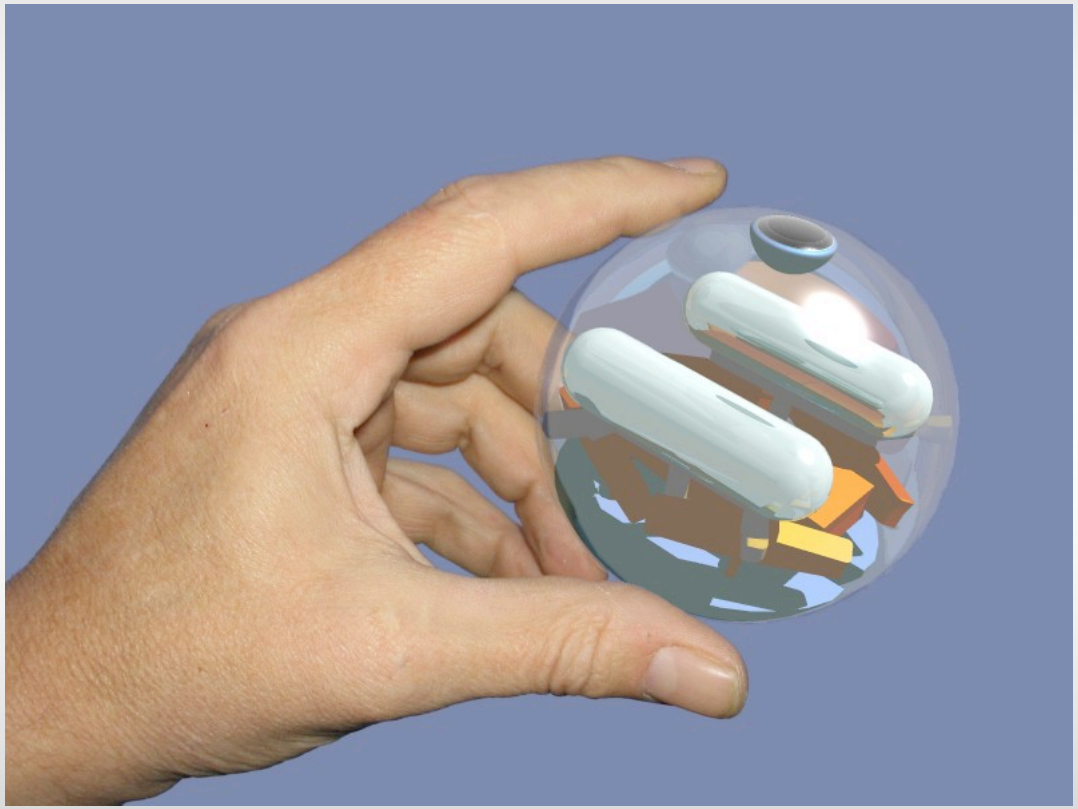




The Concept

Small, Light Weight and Reliable

- -100mm and 100 grams



Highly Redundant

- -100s-1000s of sacrificial microbots per mission
- -Made of highly durable and lightweight polymers
- -Very Agile in Rough Terrain
  - •Hopping, rolling, bouncing

Autonomous

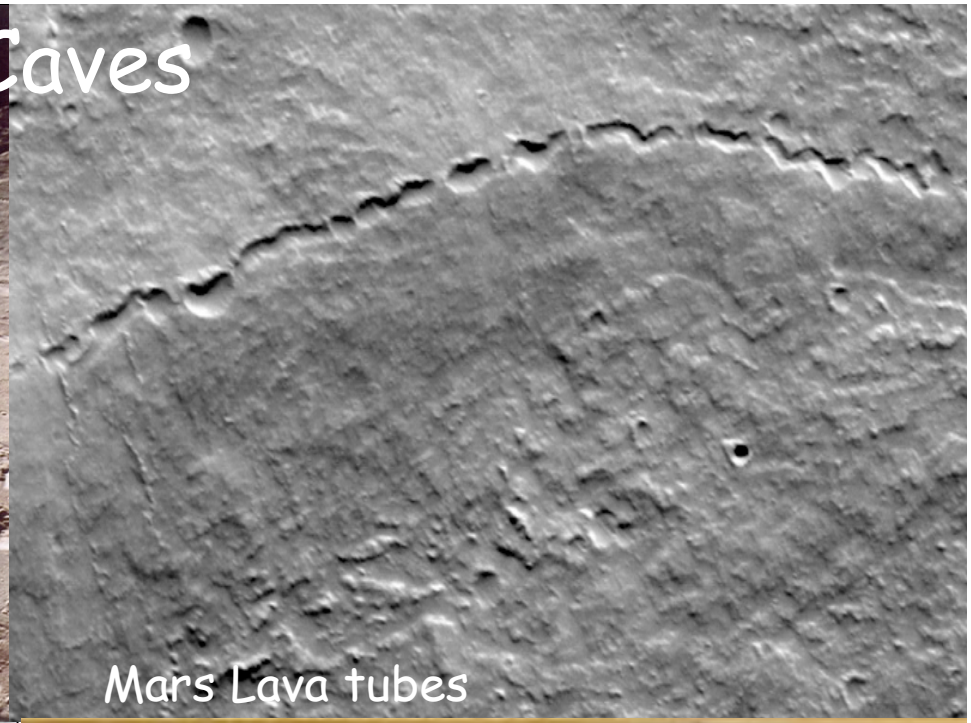
- -On-board power, communications, sensing
- -Teams with science-driven group intelligence

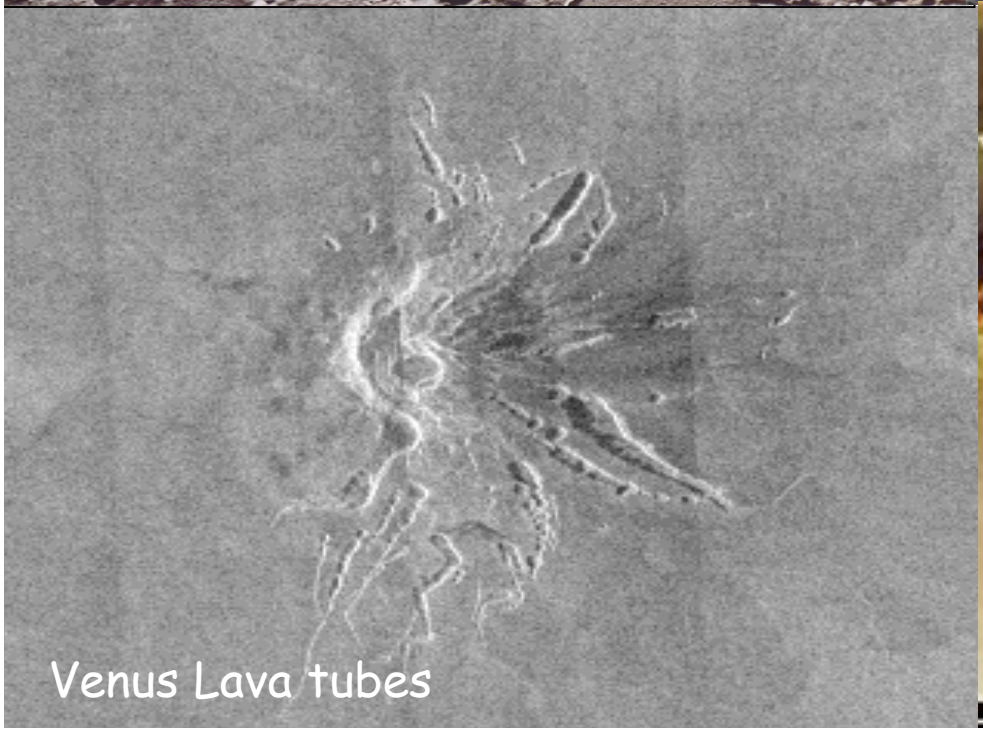
Scientific Motivation

- **Caves:**
  - **Windows into the subsurface**
    - *(underlying geology, subsurface ices/water, etc.)*
  - **Repositories for materials**
    - *(biological traces, climate signals, unique minerals, etc.)*

- **Surface terrains**
  - **Icy surfaces**
    - *(e.g. permafrost, polygons, rocky deserts, etc.)*
  - **Volcanic and rocky surfaces**
    - *(e.g. lava flows, canyons, rock underhangs, etc.)*

Scientific Motivation- Caves



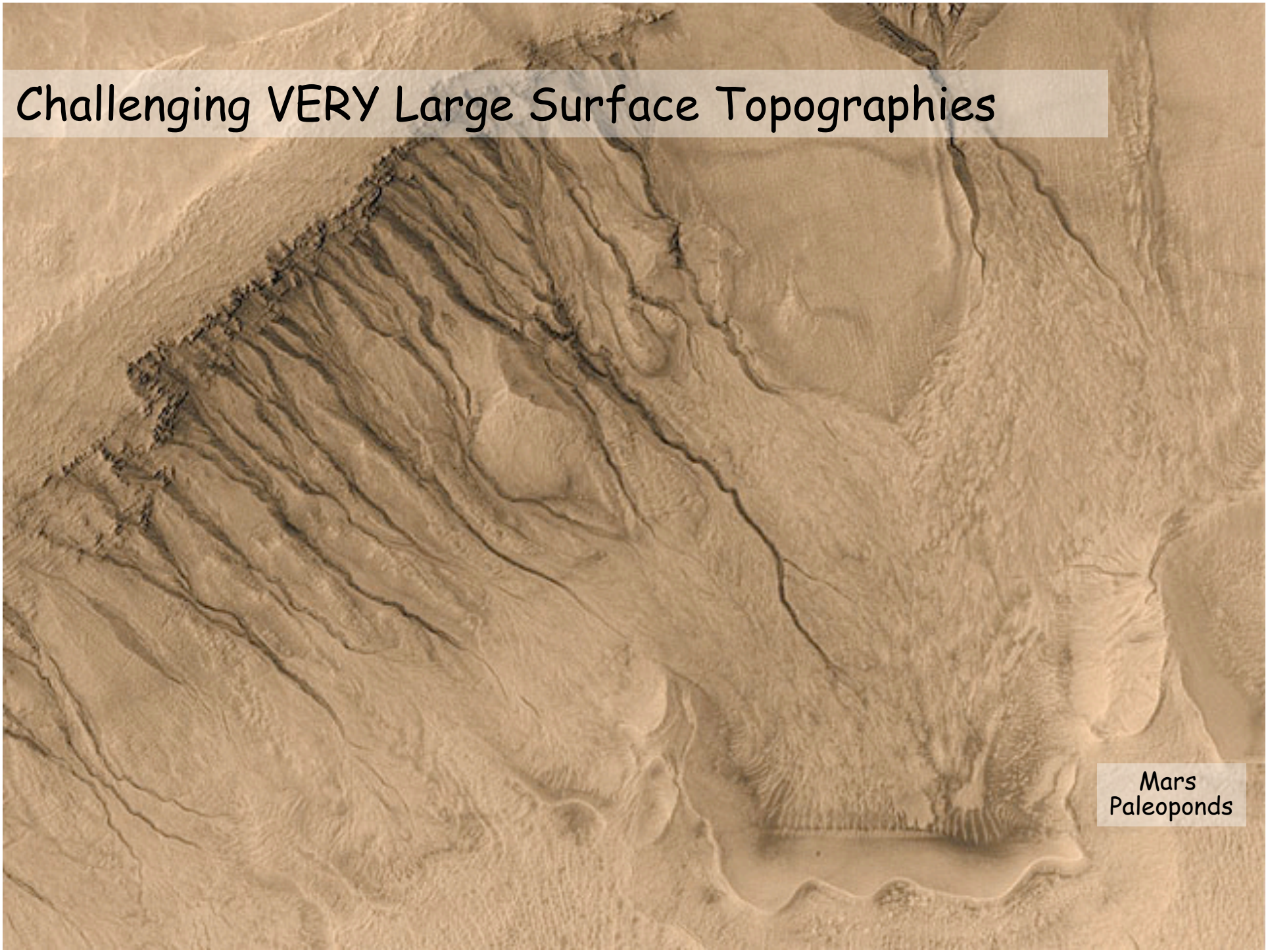


Cave Mobility

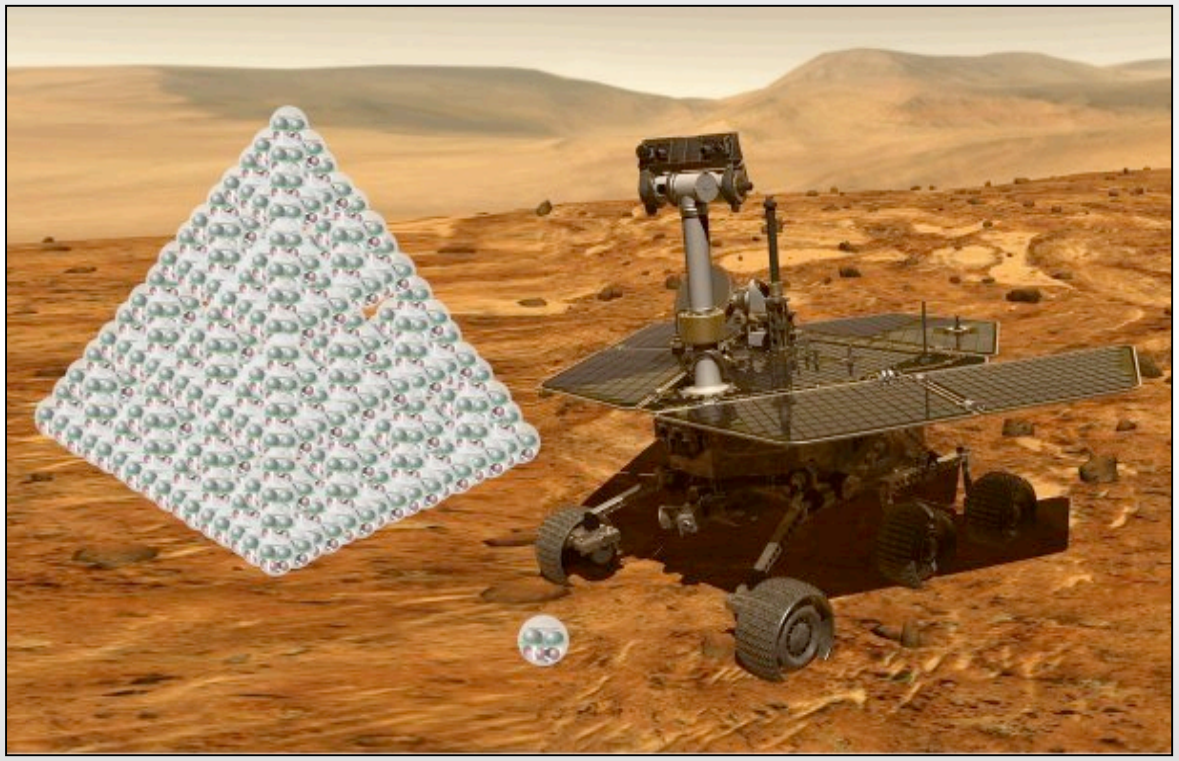
The Hibashi Cave, Saudi Arabia

Hibashi by candlelight: Show that the cave has a relatively uniform cross-section.

Challenging VERY Large Surface Topographies



MIT Microbots - A New Paradigm



1000 REMotes would have the same launch volume and weight as the Spirit

Deployment Concepts

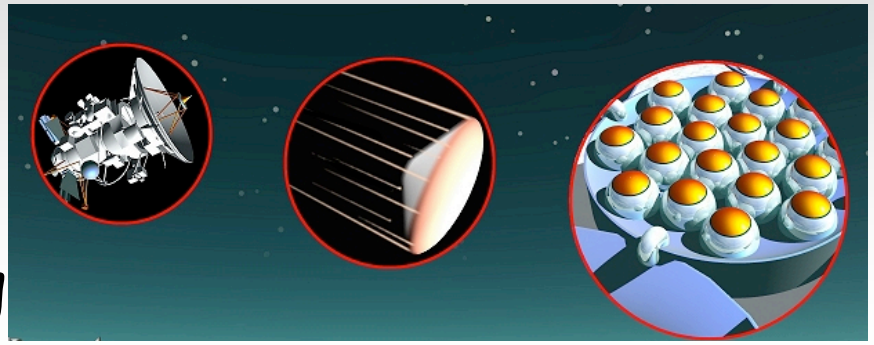
By:

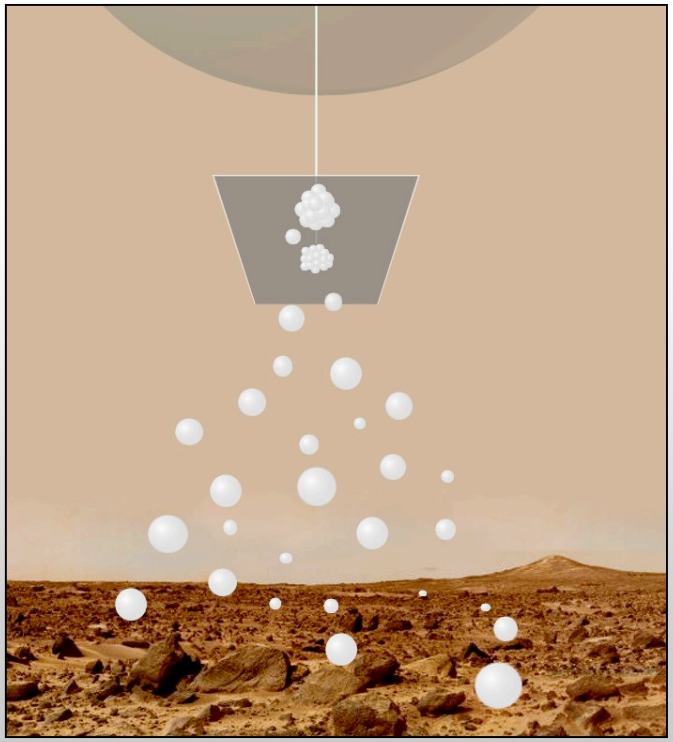
An orbiter - airbag landing

A balloon or aerial vehicle

An astronaut explorers

An autonomous rover





Microbot Subsystems

Mobility

- Bi-Stable EPAM "muscle" actuators
- Directed or non-directed hopping

Power

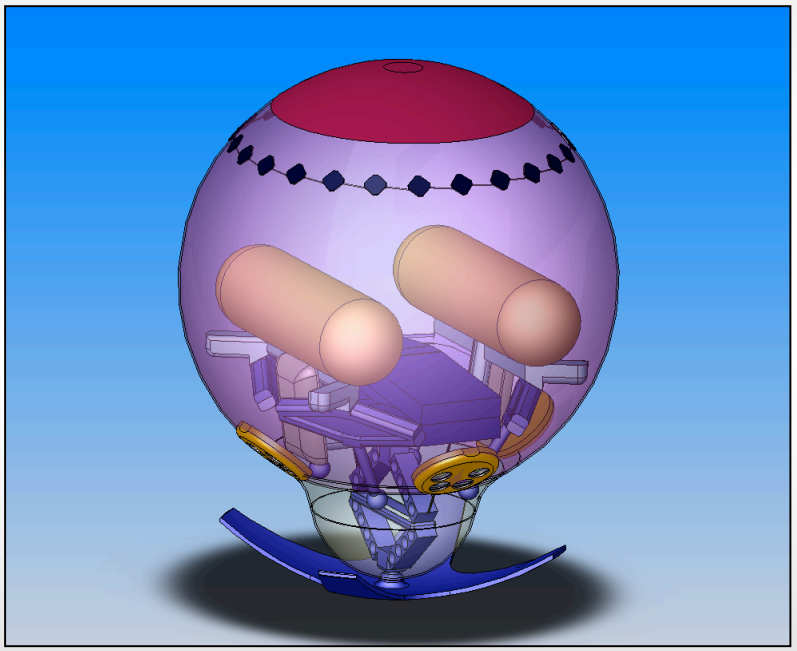
- Hyper-efficiency micro fuel cells

Sensors

- Micro-scale imagers, environmental sensors, gas analysis sensors, spectrometers

Communication and control

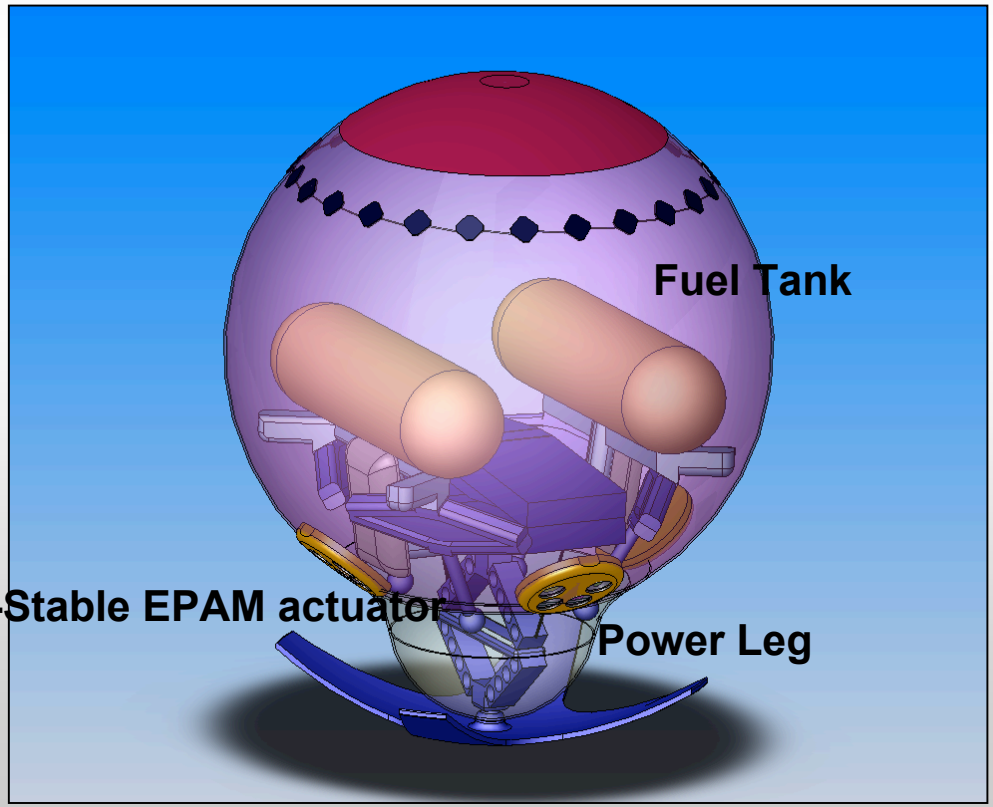
- Surface/subsurface LAN
- Collective group behavior or supervised central control

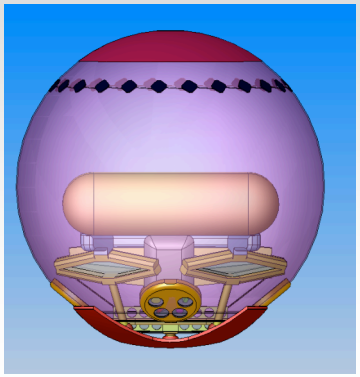


Mobility and Power

Mobility and Power

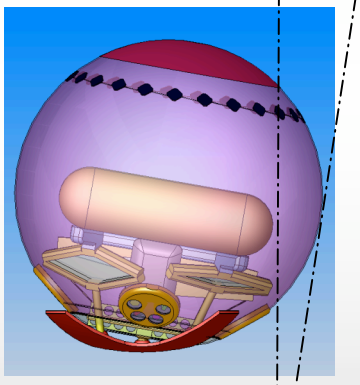
- All Polymer Bi-stable "muscle" actuators
- Directed hopping, bouncing, rolling
- High-efficiency fuel cells



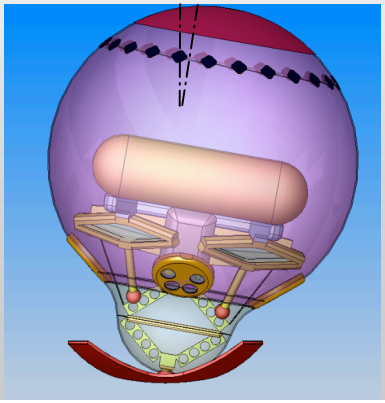


Charge

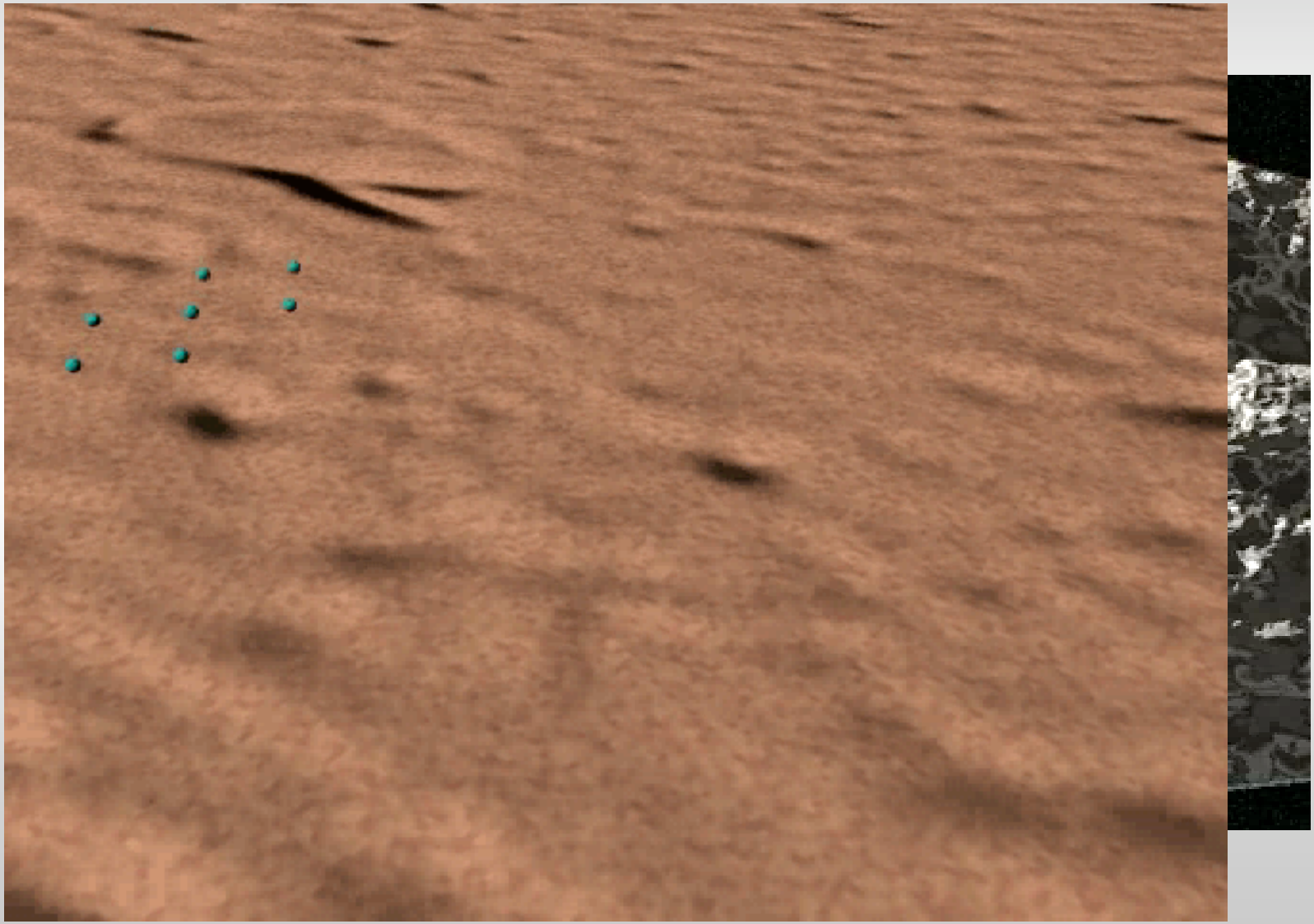
Orient



- Hop



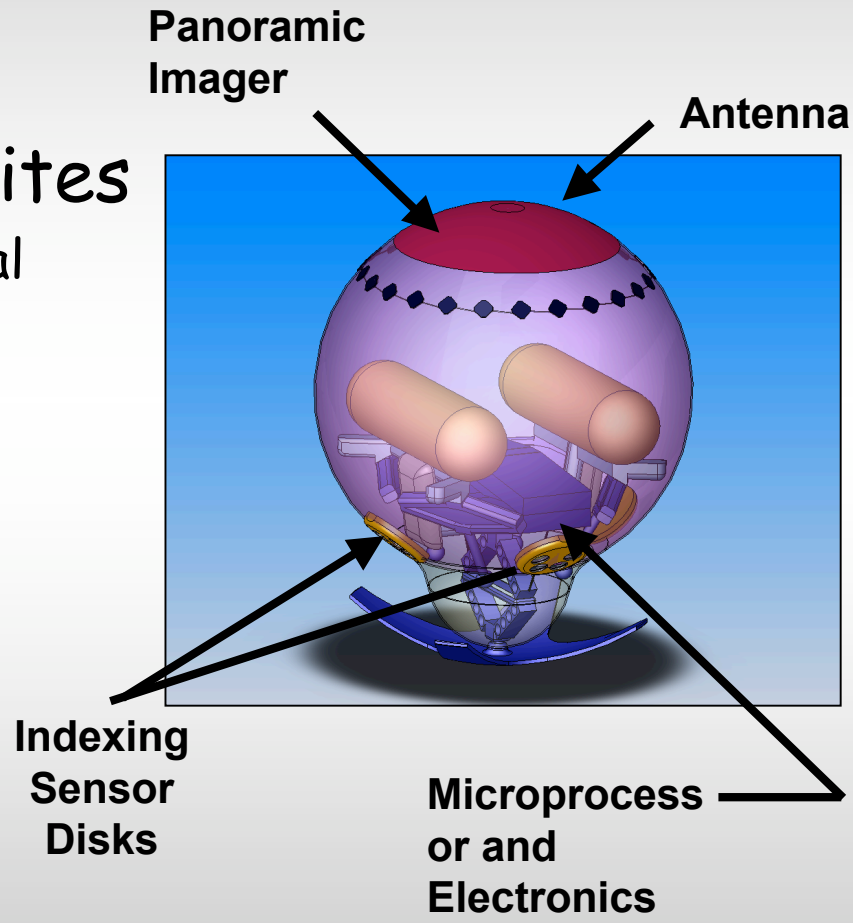
Mobility and Power



Sensors and Communications

Heterogeneous sensor suites

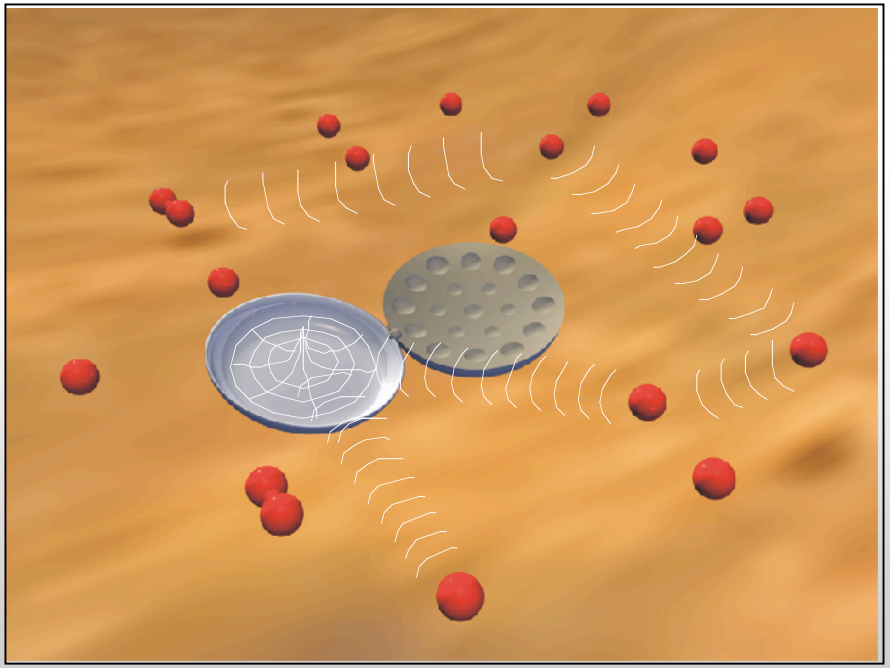
Micro-scale imagers, environmental sensors, gas analysis sensors, spectrometer, etc.



Surface/subsurface LAN

- Trail of breadcrumbs"
- To a Lander or to aerial vehicle or orbiting satellite mother ship.

Microbot surface LAN



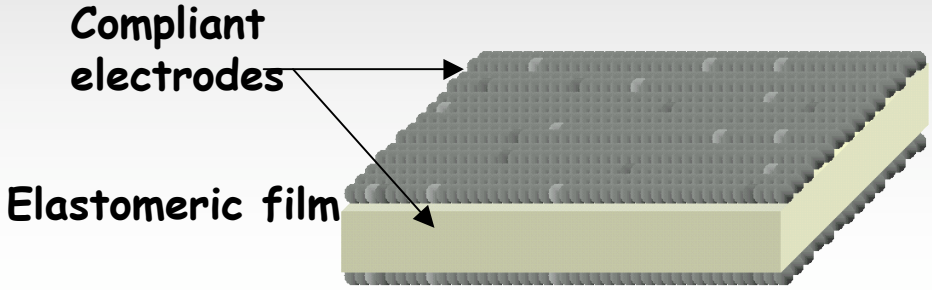
Key System Components

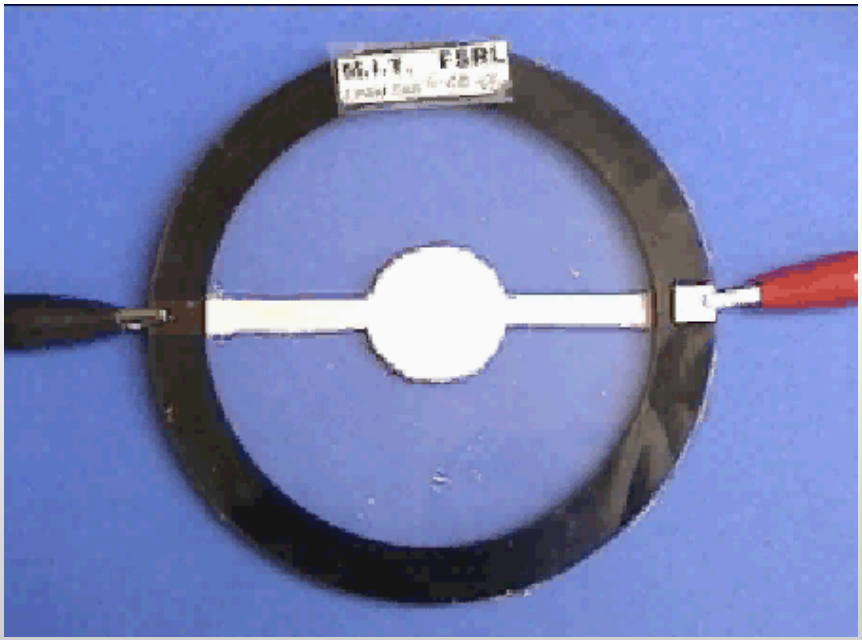
Actuation

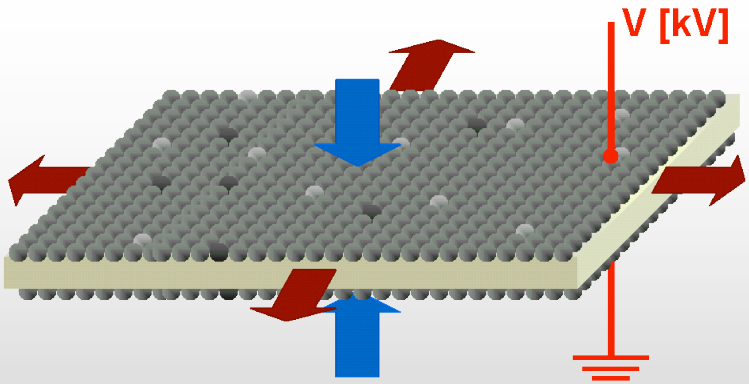
Actuator: Electroactive Polymer Artificial Muscles (EPAMs)

- Simple
- Lightweight

Basic Operating Principle







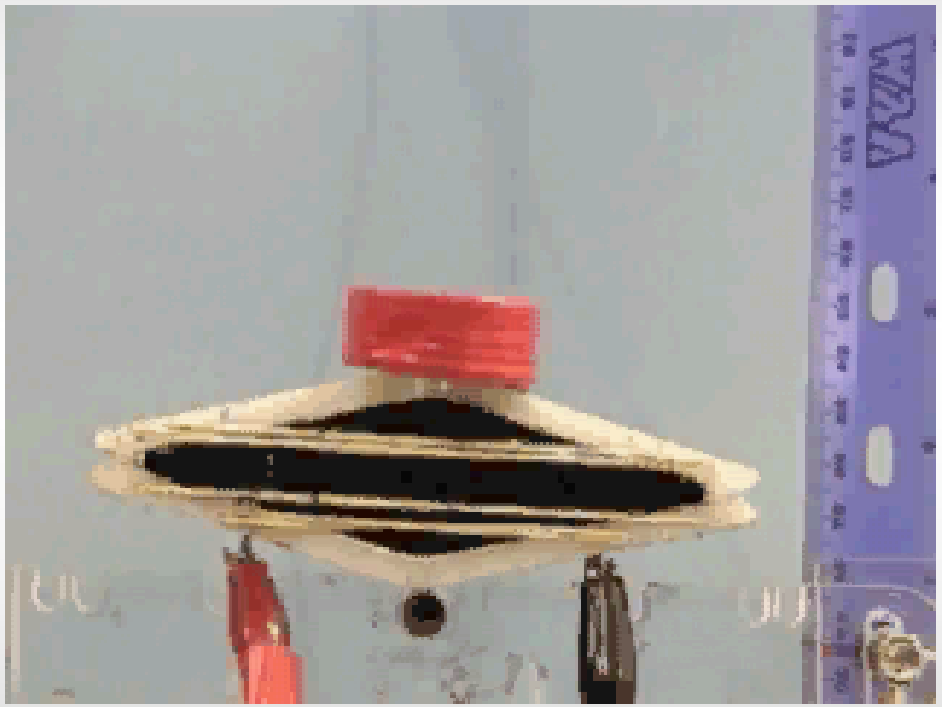
Mobility-Hopping, Bouncing and Rolling

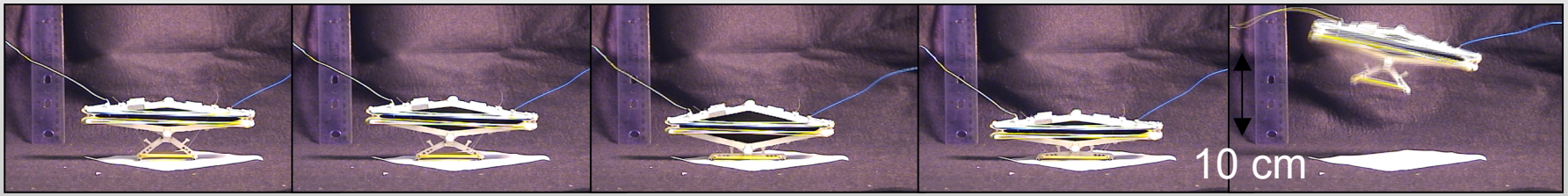
Key to the Concept: Dielectric Elastic (Polymer) Actuators (DEA's)

- -Very Low Const
- -Simple
- -Very Lightweight

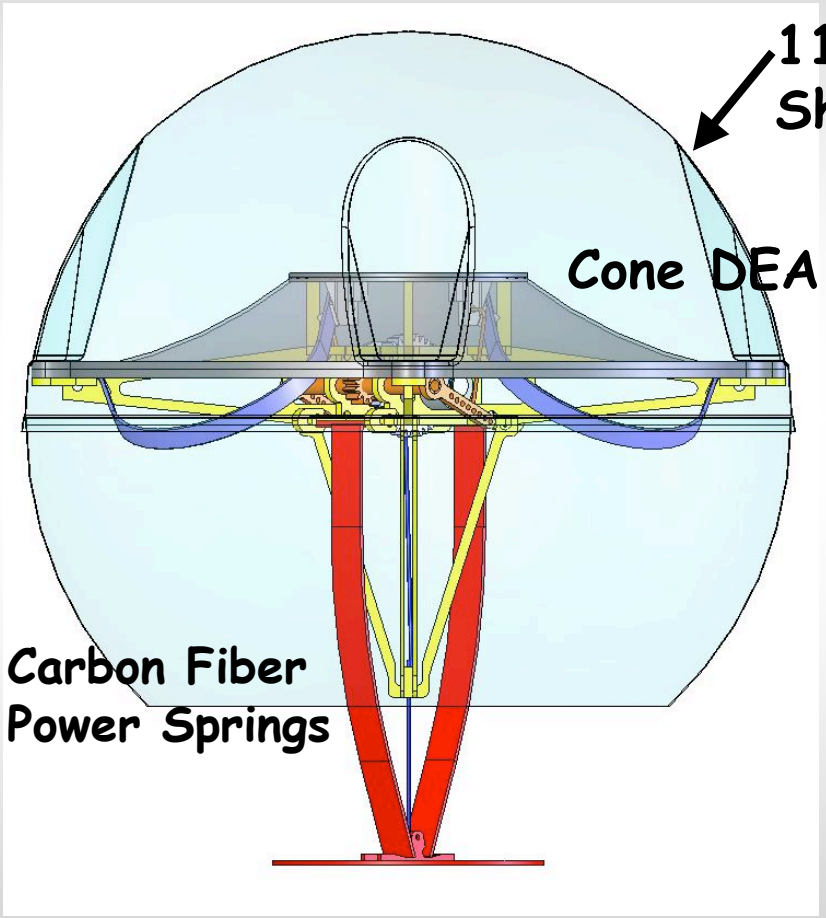
MIT actuator performance

- -Large strains (up to 200%)
- -Micro-amp currents
- -1000:1 force to weight ratio
- -Dynamic response: 10 Hz

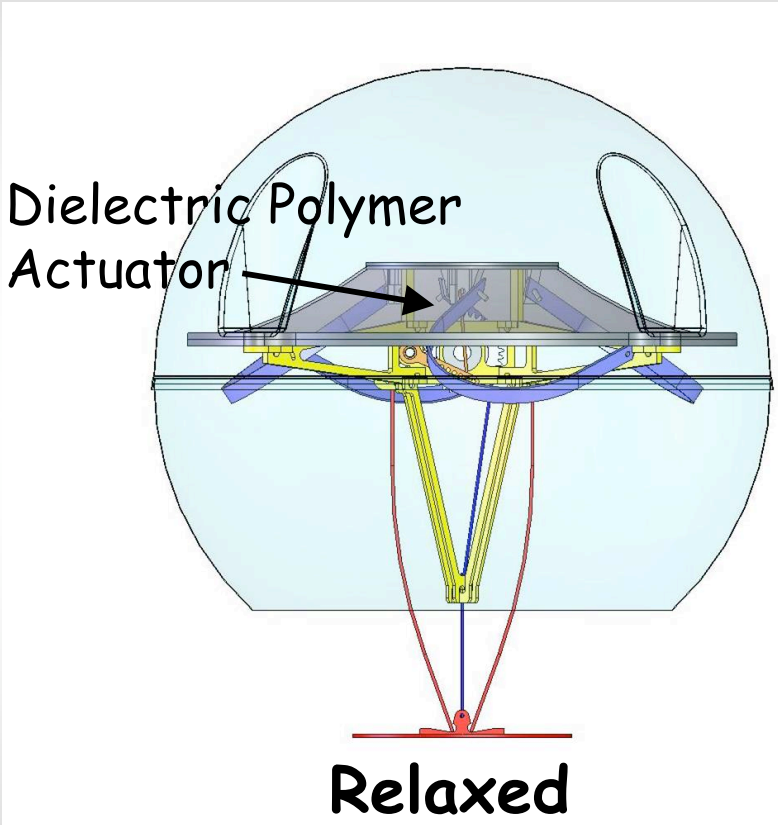




Proof-of-Concept Hopping Design



Mobility Mechanism



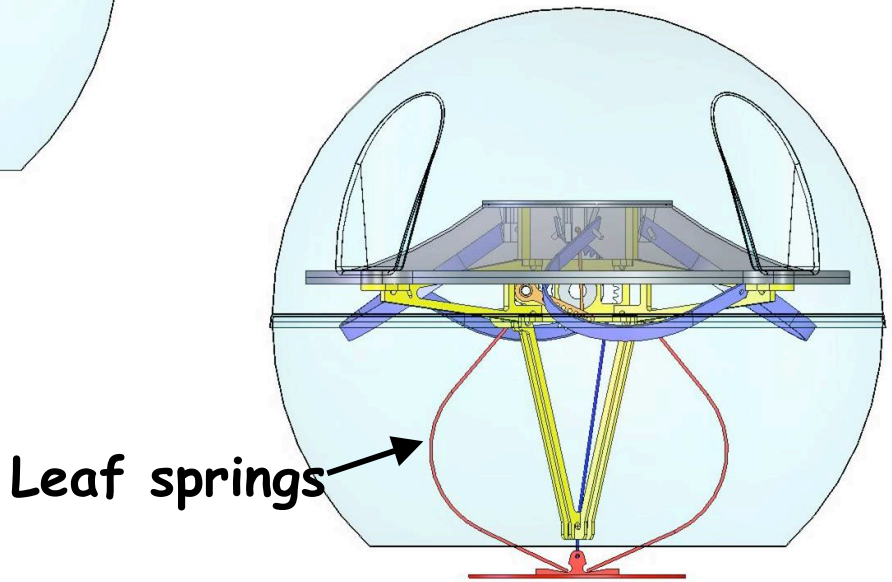
Relaxed

DEA Actuator (Two Layers)

- Forces: 5N
- Strains of 50 %

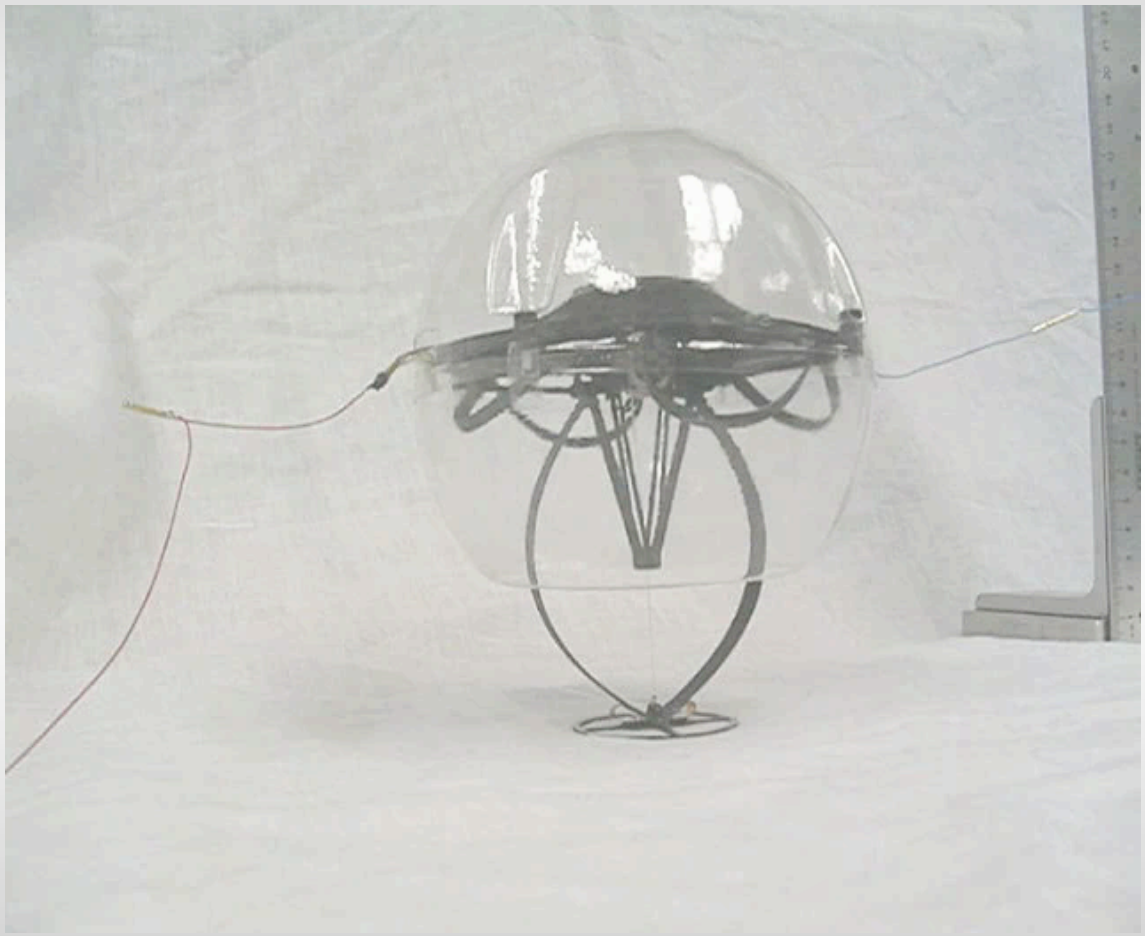
Leaf springs (Carbon fiber)

- Bending Energy Stored 0.2 J/g
- Spring mass: 0.9 gram



Charged

Prototype Proof-Concept Experimental System



Total mass	26 grams
Actuator mass two Layers	6 grams
Transmission and structure	12 grams
Shell	8 grams
Hop height	≈ 1 Meter

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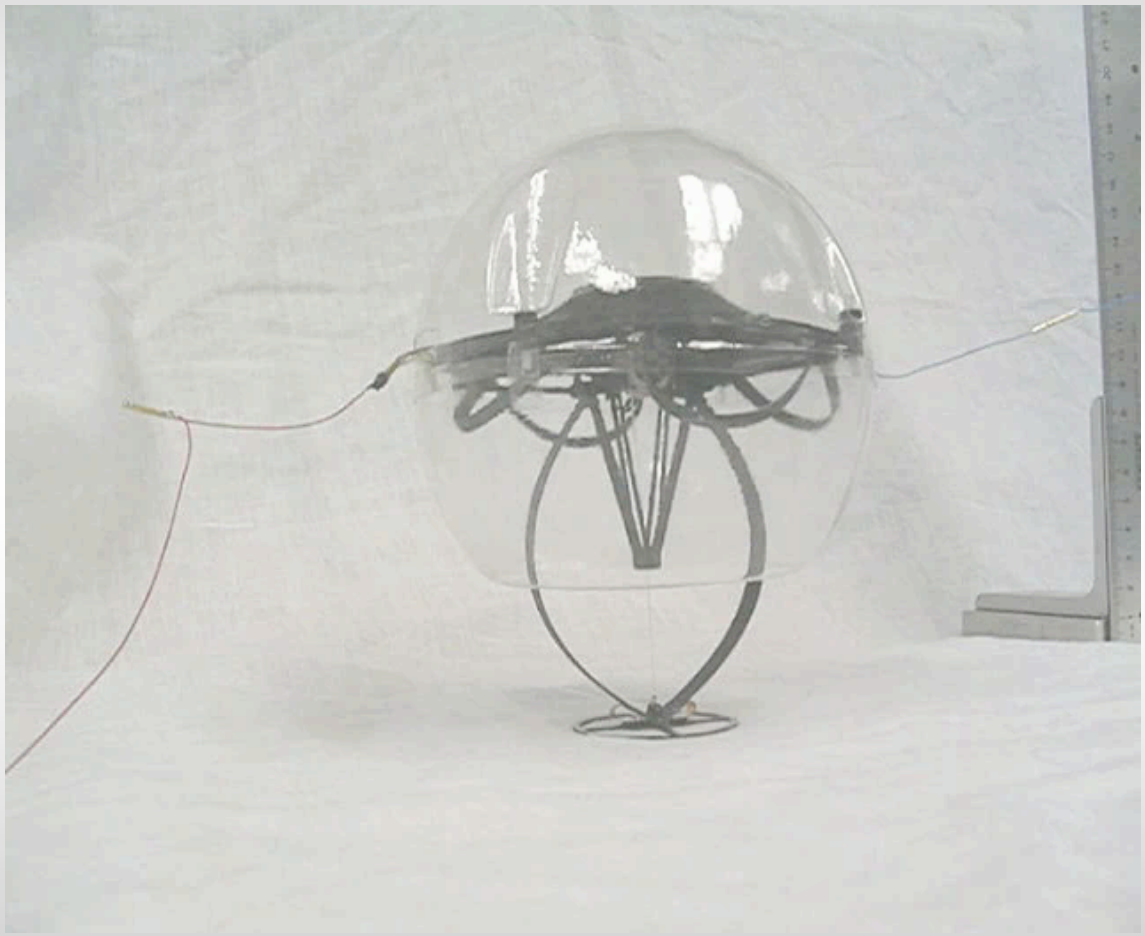


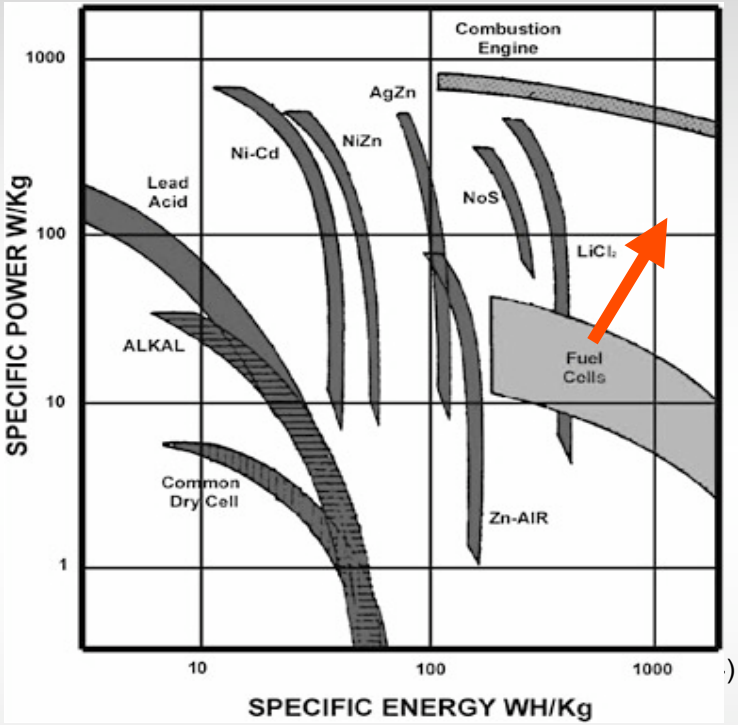
We need a longer ruler!

Hybrid Fuel Cell Power

Advantages

- High energy density
- High thermodynamic efficiency
- No moving parts
- Minimum emissions
- Quick recharge

Fuel cells outperform batteries in low to medium power applications with long mission duration



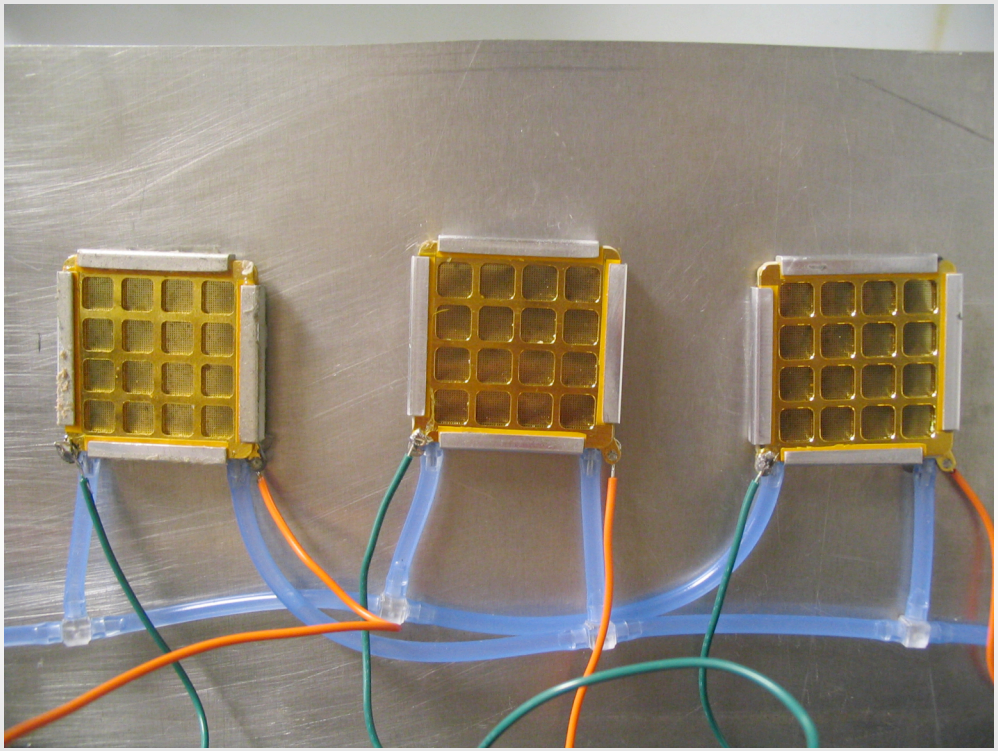
Field Prototype Design Specs

- average elect. power: 0.11 W
- peak elect. power: 0.5 W
- total elect. energy : 77 Wh_{el}

Peak power is 5 times average power: Hybrid system (fuel cell optimized for average power and a battery optimized for peak power with trickle fuel cell charging)

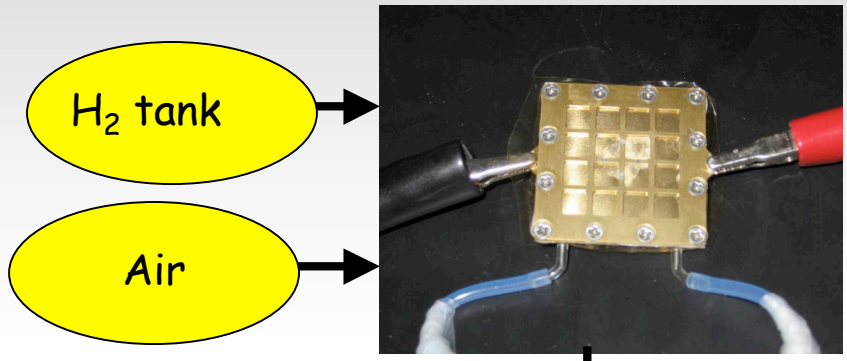
Type	Electrolyte	Operating Temp.	Stack Efficiency	Fuel Compatibility	Fuel Storage
PEM	polymer	70-120°C	50-70%	air/H_2	NH_3BH_4

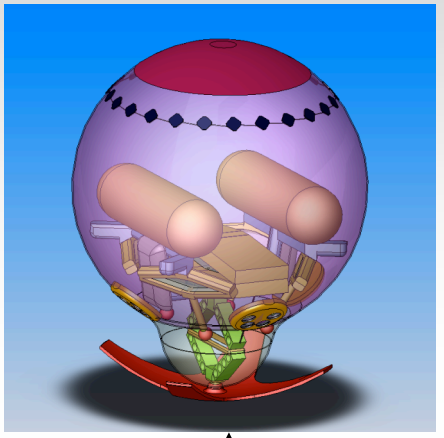
Fuel Cell Power

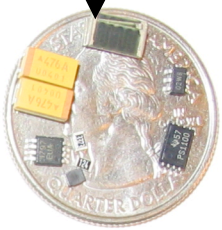


Type	Electrolyte	Operating Temp.	Stack Efficiency	Fuel Compatibility	Fuel Storage
PEM	polymer	70-120°C	50-70%	Air or O/H_2	NH_3BH_4

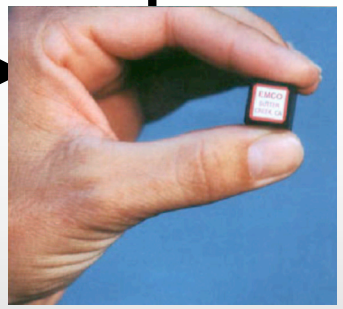
System Schematic







Hopping Control (0.5 gram)



HV Converter (9grams)

Hybrid Fuel Cell Power

Powers all subsystems: Mobility system, Sensors, Electronic and communication, heating, etc.

Average power: 0.11W

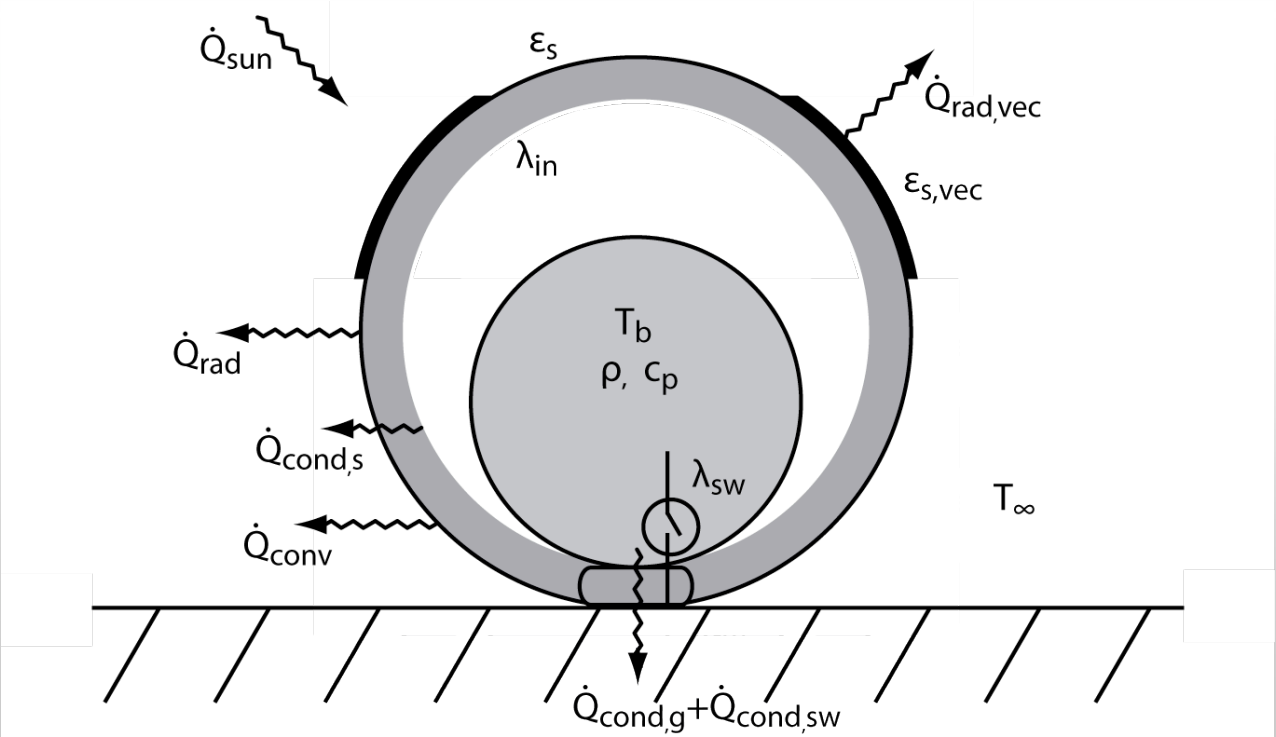
Peak power: 0.5W

Total electrical energy required for a typical 30 day mission: 77 Wh

Fuel Cell Based Metabolic Thermal Control

Thermal Concept:

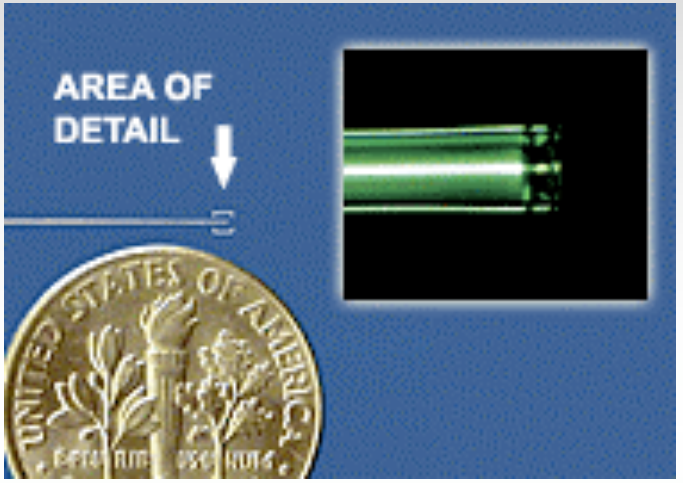
- Metabolic control: regulation of hopping rate in order to keep the microbot from freezing, while not overheating it
- Internal temperature range: -50 to +50 C
- An insulation and heat rejection system appropriate for the mission environment



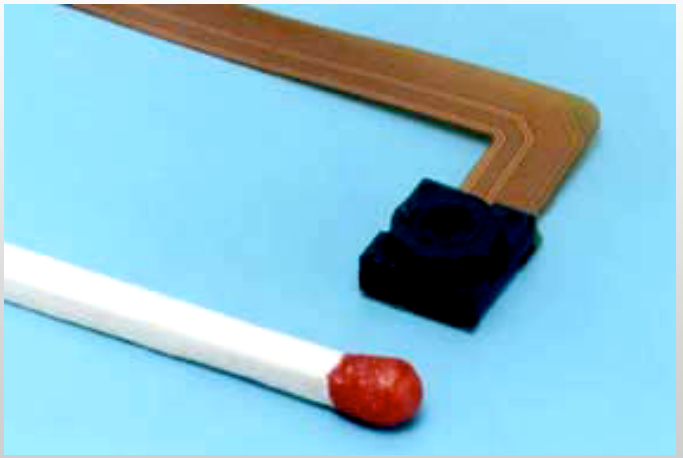
Sensors and Electronics

Sensor Requirements

- Miniaturization
- Low Power
- Impact & Shock Resistant
- Scratch & Abrasion Resistant
- Dust repellant
- Reconfigurable systems based on modules with standardize interfaces.
- "Tailor" Microbots for different missions
- No *from-scratch* redesign



High temp. pressure sensor.
125 microns diam.



Fuji CCD Camera

Sensors and Electronics

The Concept Exploits the Recent Rapid Advances in micro-electronics and micro-sensors.

Mobility & position sensors

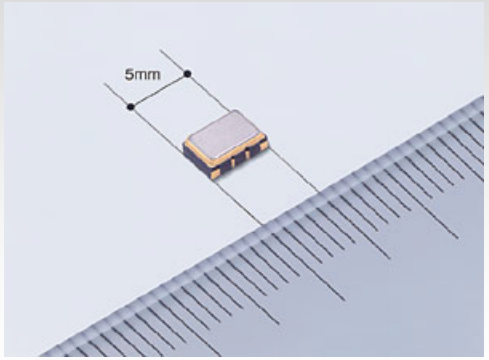
- Accelerometers
- IMU (inertial measurement unit

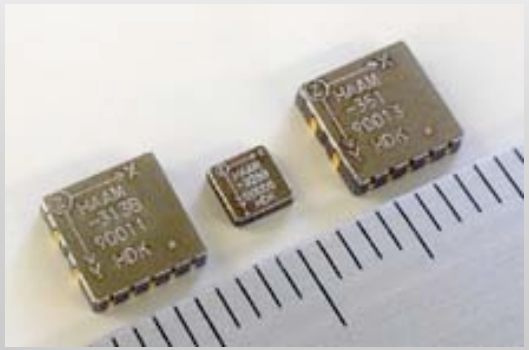
Environmental and physical sensors

- Pressure
- Temperature
- UV detectors

Search and rescue mission specific sensors

- Cameras
- Gas analyzers
- Human DNA
- CO emissions
- Temperature sensors and imagers
- Etc.

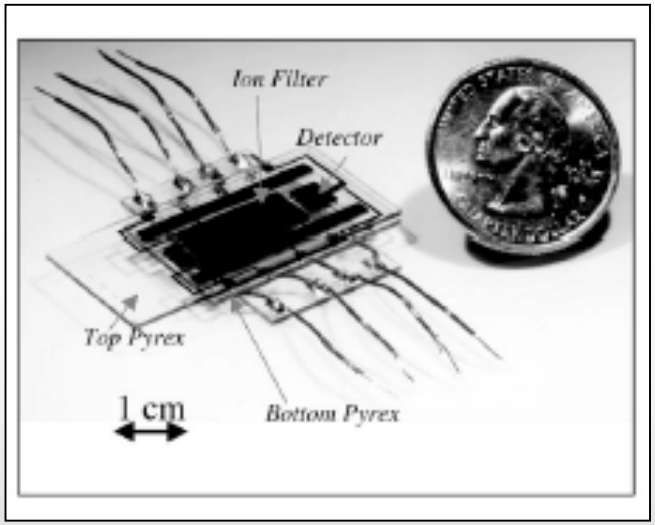




Sensors

- Gas analysis
  - Primarily for detection of carbon compounds
  - Detection of methane to study biological activity
  - Micro-scale *laboratory-on-chip* type sensors are under development

- X-Ray, Raman and Mössbauer spectrometers
  - Play key roles in planetary geo-chemical characterization
  - Greatest limitations for miniaturization and largest power consumption
    - "Spectrobots" to carry only spectrometers
    - Specific measurement and limited spectra resolution could be key for data reduction

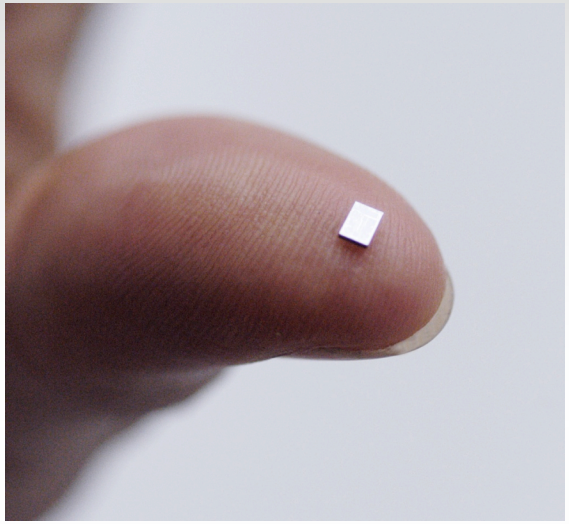


Miniaturized mass spectrometer- Draper Laboratories

Data Processing and Storage

Simple computation tasks:

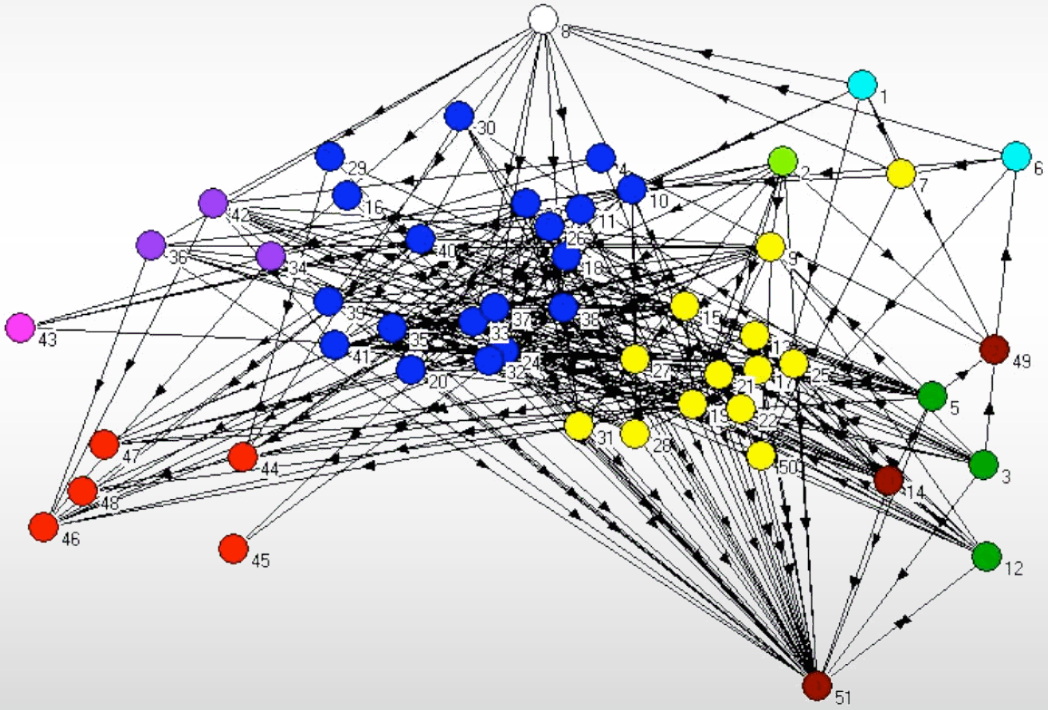
- Taking measurements
- Swarm navigation
- Communication
- Ultra low power processor



Data storage:

- Fractions of a gigabytes of storage
- Highly compact and light
- Low power consumption
- Stable and robust

Scientific Motivation



Meteorology nets

Seismic nets

Physical parameters
e.g. radiation environment

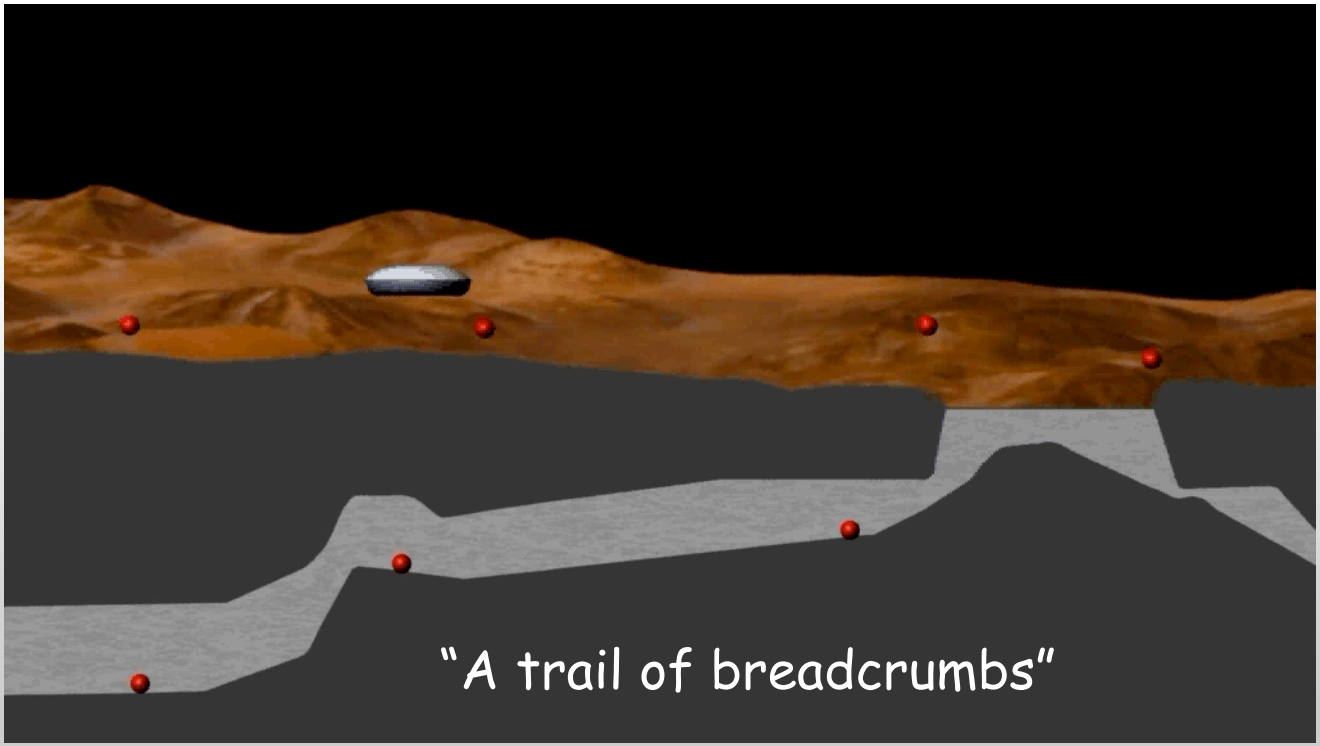
Communications

Surface Communication:

- Max distance: 1 km
- Radio communication
- Low power requirements

Subsurface Communication"

- Microbots communicate with surface by a "- a Microbot LAN
- Acoustic



Reference Mission Evaluation

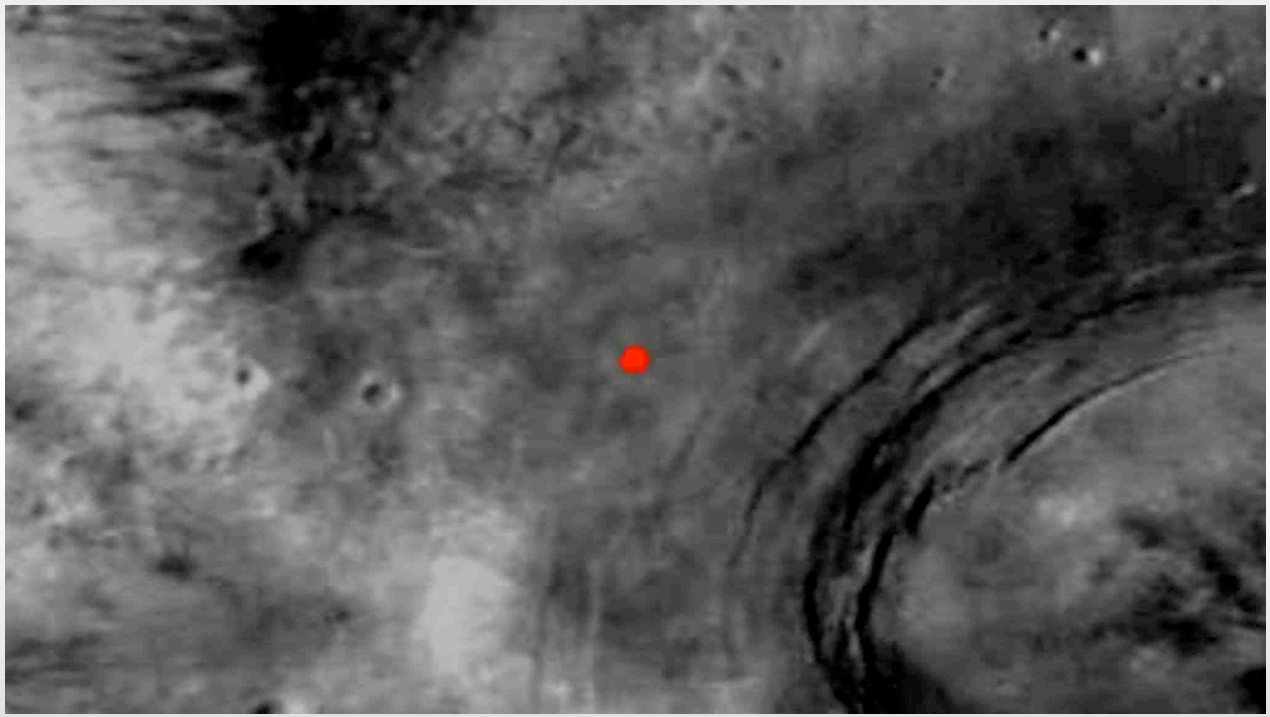
- A Mar surface exploration mission - 135 sq kilometers (50 sq miles) in 30 Sols
- A Cave exploration mission - 1 Km in 5 days (WEEBUBBIE CAVE-Australia)

Surface Mobility Reference Mission--Simulation Results

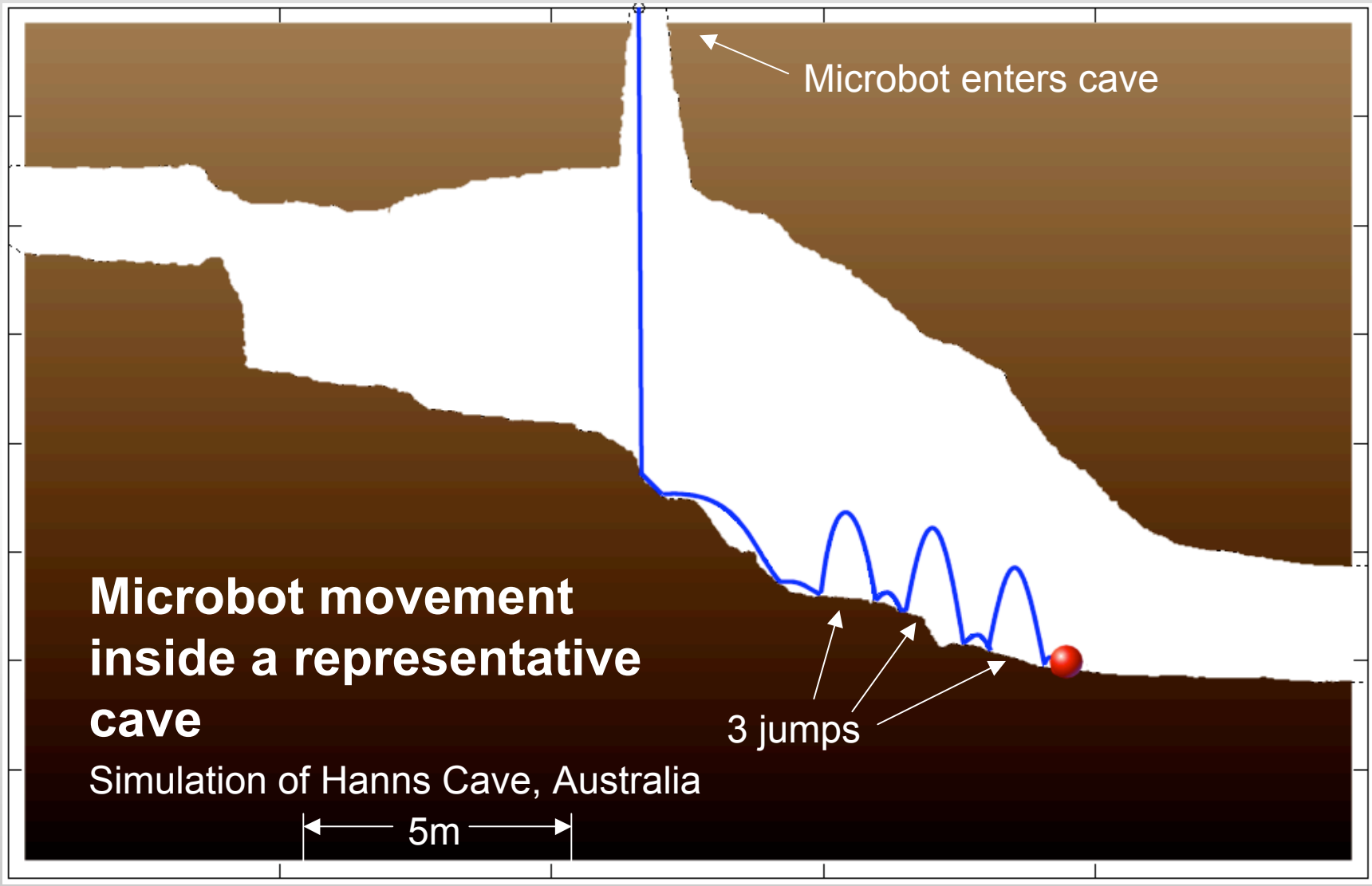
Reference Mission:

- 133 square km or 50 square mi covered covered in 30 Sols
- 100 Microbots
- 1.5 m per jump
- 4320 jumps
- 6 jumps / hour
- 30 days

- Result for one "team"
- Mission might have multiple teams with various starting on planet



Cave Mobility -- Simulations Study Results



Surface Mobility--Simulations Study Results

Analysis of microbot surface mobility

- 100 Microbots
- 1.5 m per jump
- 4320 jumps
- 6 jumps / hour
- 30 days

133 square km or 50 square mi covered

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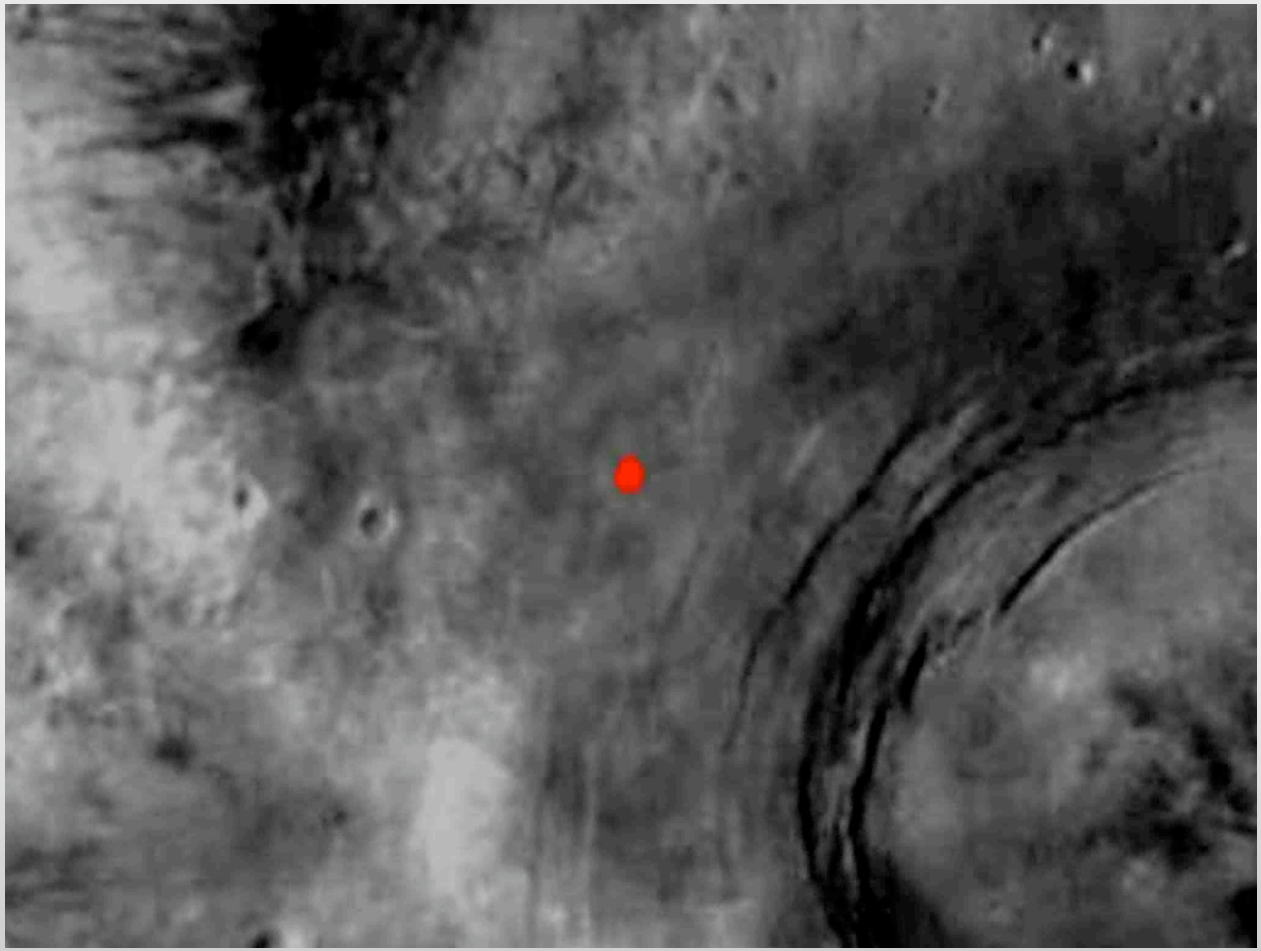
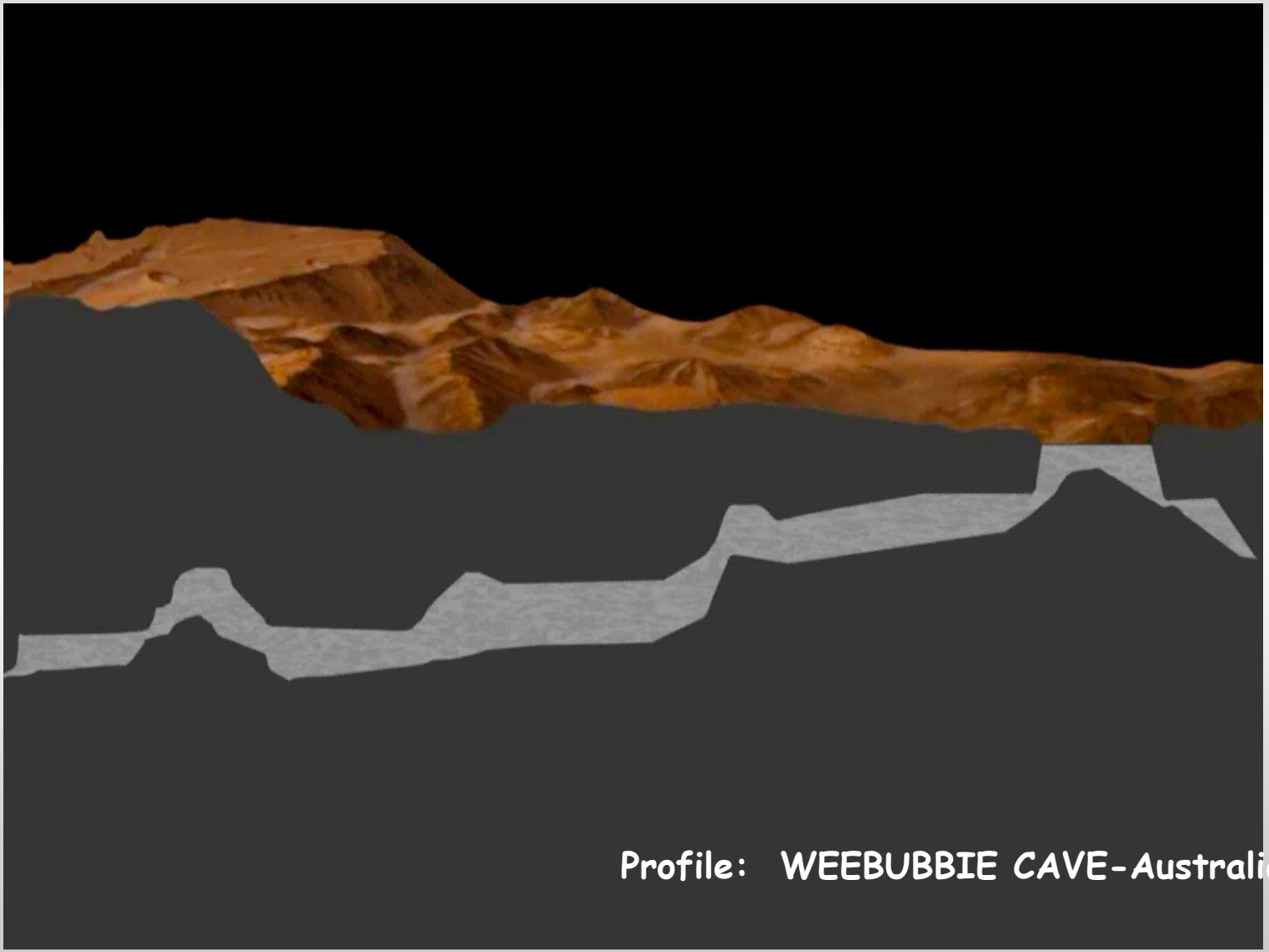
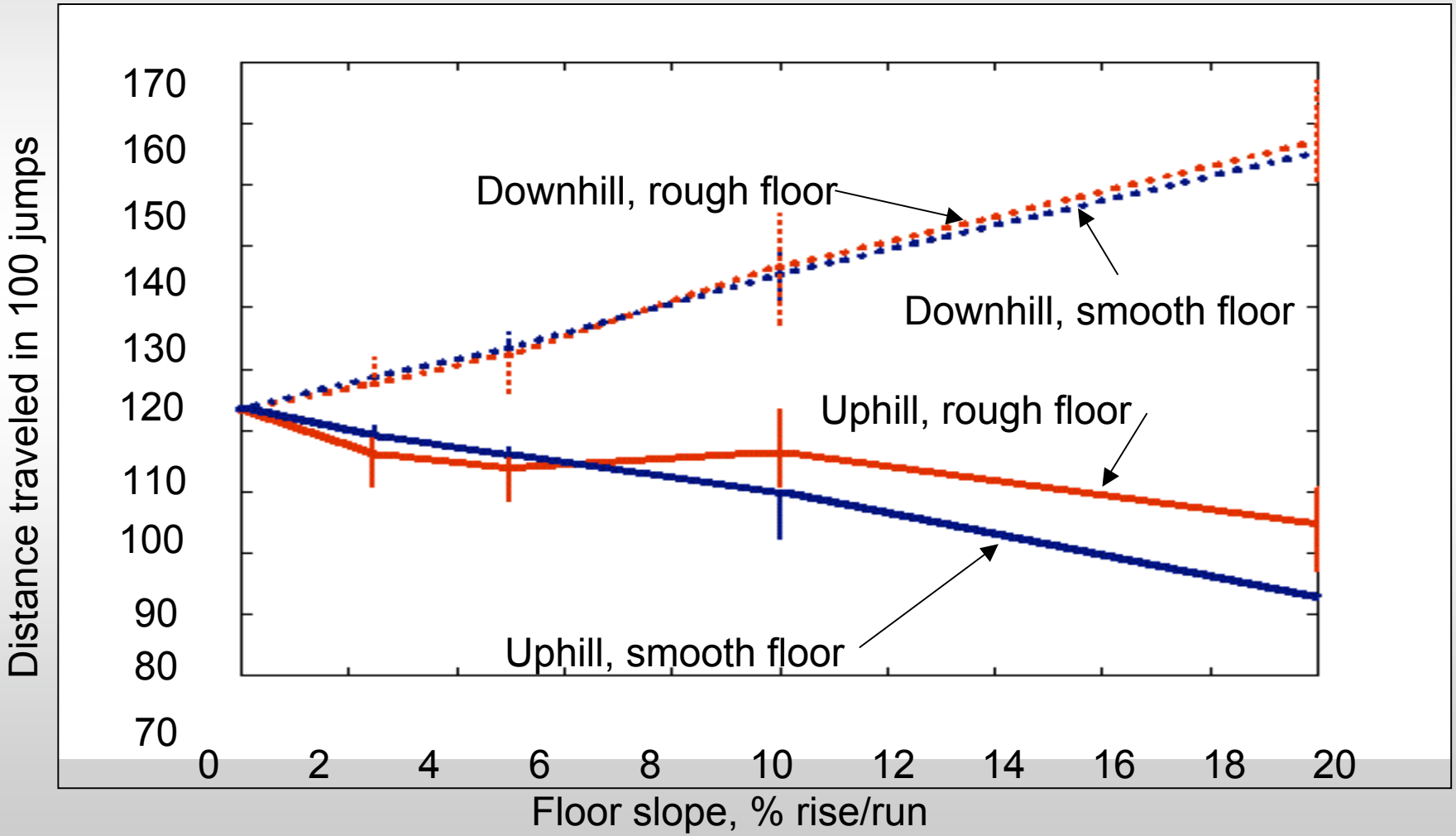


Cave Mobility



Cave Mobility Studies

Effect of slope on microbot travel - Sandy cave floor



Preliminary Field Testing - New Mexico Lava tubes

- Breakdown floors vs. sediment floors
- Wedging issues in different terrain
- Size optimization of microbot units

Terrestrial Spin-off of the Technology

Search, rescue, and reconnaissance in buildings, mines, caves

The use of very low- cost sacrificial Microbots is potentially very effective.

MRI Compatible Manipulator for Prostate Cancer Detection & Treatment

Prostrate Cancer

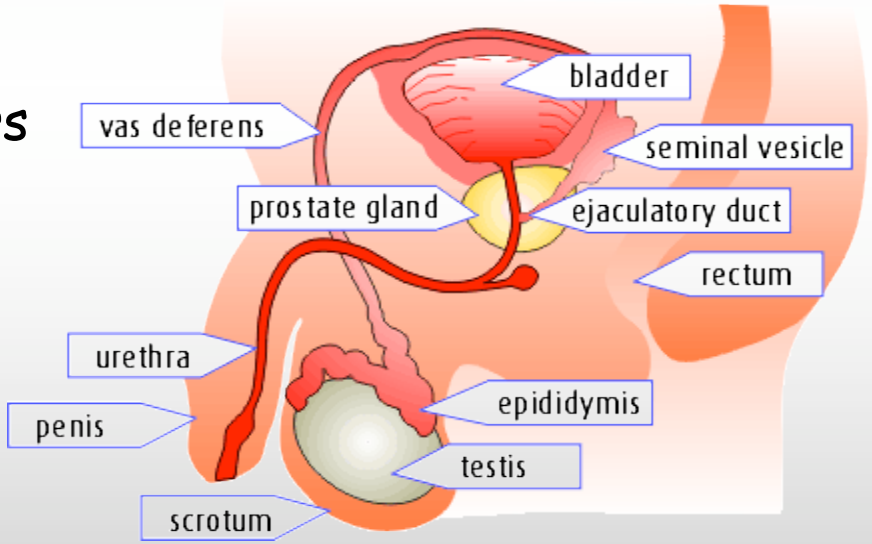
- Most frequently diagnosed cancer in men
- The number 2 cause of cancer death in men

Current Treatment Methods

- Hormone Drug Therapy - 1 to 2 yrs
- Radical Radiation Therapy and Prostatectomy
- Etc

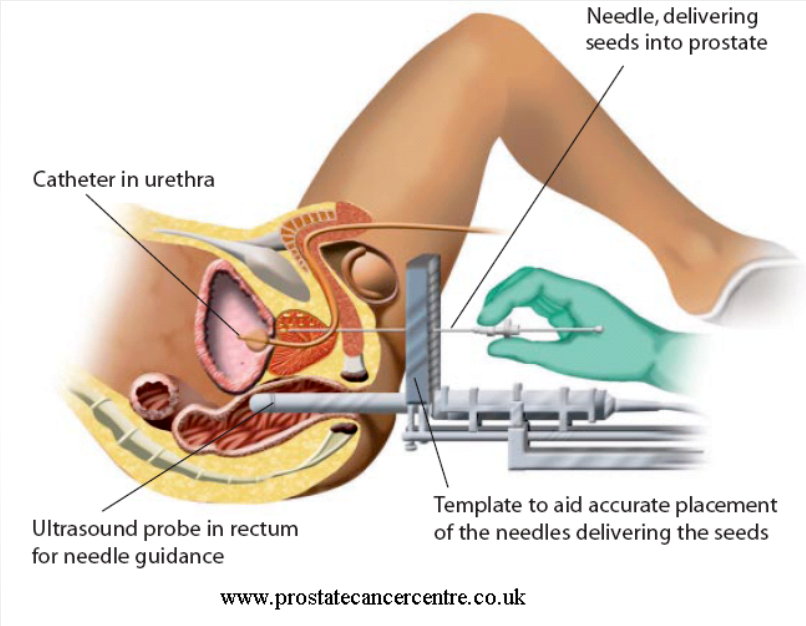
Undesirable Side Effects

- Incontinence
- Impotence



Guided Brachytherapy Therapy

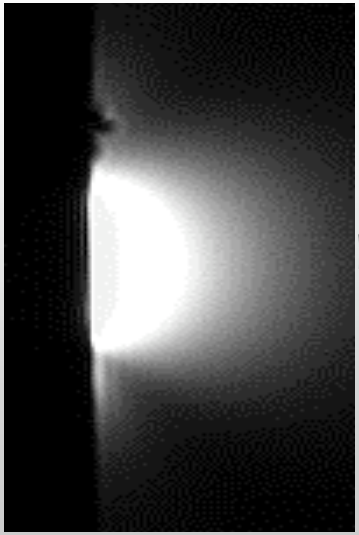
- Transperineal



Ultrasound guided is too imprecise cm scale tumors

MRI - mm tumors

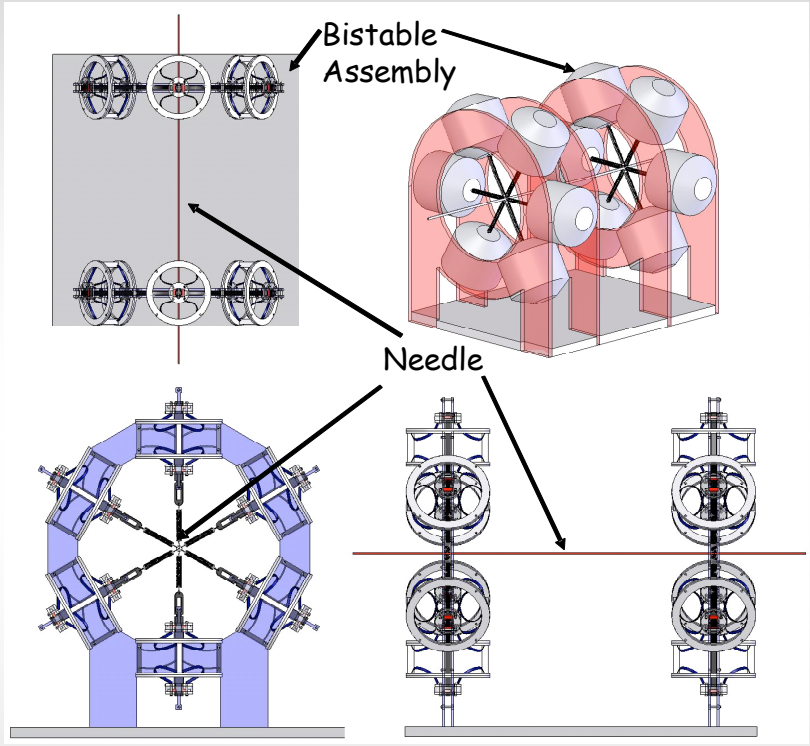
•Dielectric Elastomer Actuators (DEA) are MRI Compatible

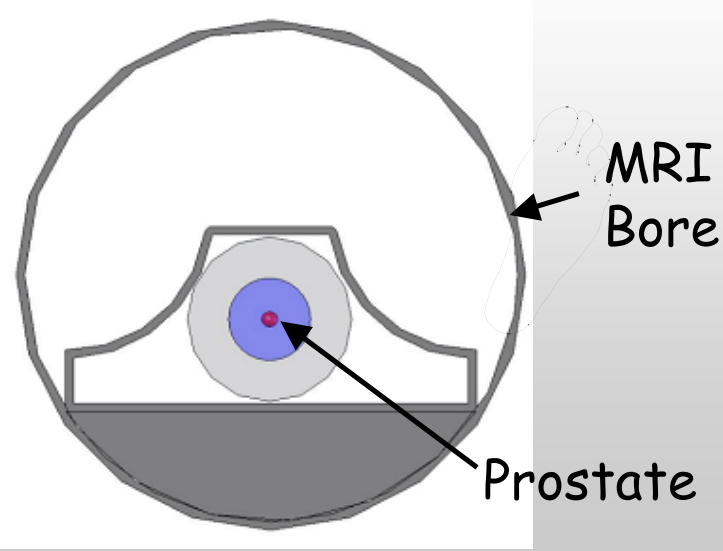


With actuated DEA

An MRI prostate cancer treatment manipulator based on NIAC DE Actuators

- MRI Compatible
- Robust
- Inexpensive
- Simple





BWH
BRIGHAM AND
WOMEN'S HOSPITAL
A Teaching Affiliate of Harvard Medical School

Summary

The MIT Microbots: A new design paradigm for the exploration of the planetary, Explorers

"They could go where no robot has gone before"

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