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02-1461

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Planetary Sample Transfer Acquisition and Handling

In-Situ Sampling/Sample Processing Strategies and Technologies for:

Venus
Comets/Asteroids
Titan

Team: W. Zimmerman, Lead Engineer

Pat Beauchamp
Yosi Bar-Cohen
Don Bickler
Jack Jones
Dave Rodgers
Greg Bearman
Mike Hecht
Ron Ross

Jet Propulsion Laboratory/California Institute of Technology

April 30, 2002

Organization of Presentation

- What is the Technology Area
  - Vision
  - Scope
- Current State of this Technology
- Benefits to Solar System Exploration Missions
- Technology Capabilities / Needs
- Technology Development Plan / Roadmap
- Key Products / Major Milestones of this Program
- Funding

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Planetary Sample Acquisition/Processing: Vision/Overview/Scope

- **Vision/Overview**
  - If we only have one chance to successfully complete an in-situ mission to an outer planetary body, then we must take advantage of that one opportunity to perform in-situ sampling/analysis. In order to form valid scientific conclusions about planetary origin, chemical/ physical make-up, and possible presence of pre-biotic signatures, we must have a robust means of obtaining samples, and we must preserve that sample from the beginning to the end of the sample processing cycle.
  - The extreme environments of these bodies (cold, heat, micro-g) present a significant challenge for in-situ sampling/science devices.
- **Scope**
  - Technology area focuses on in-situ sample acquisition/processing for:
    - Venus
    - Small bodies (comets, asteroids)
    - Titan

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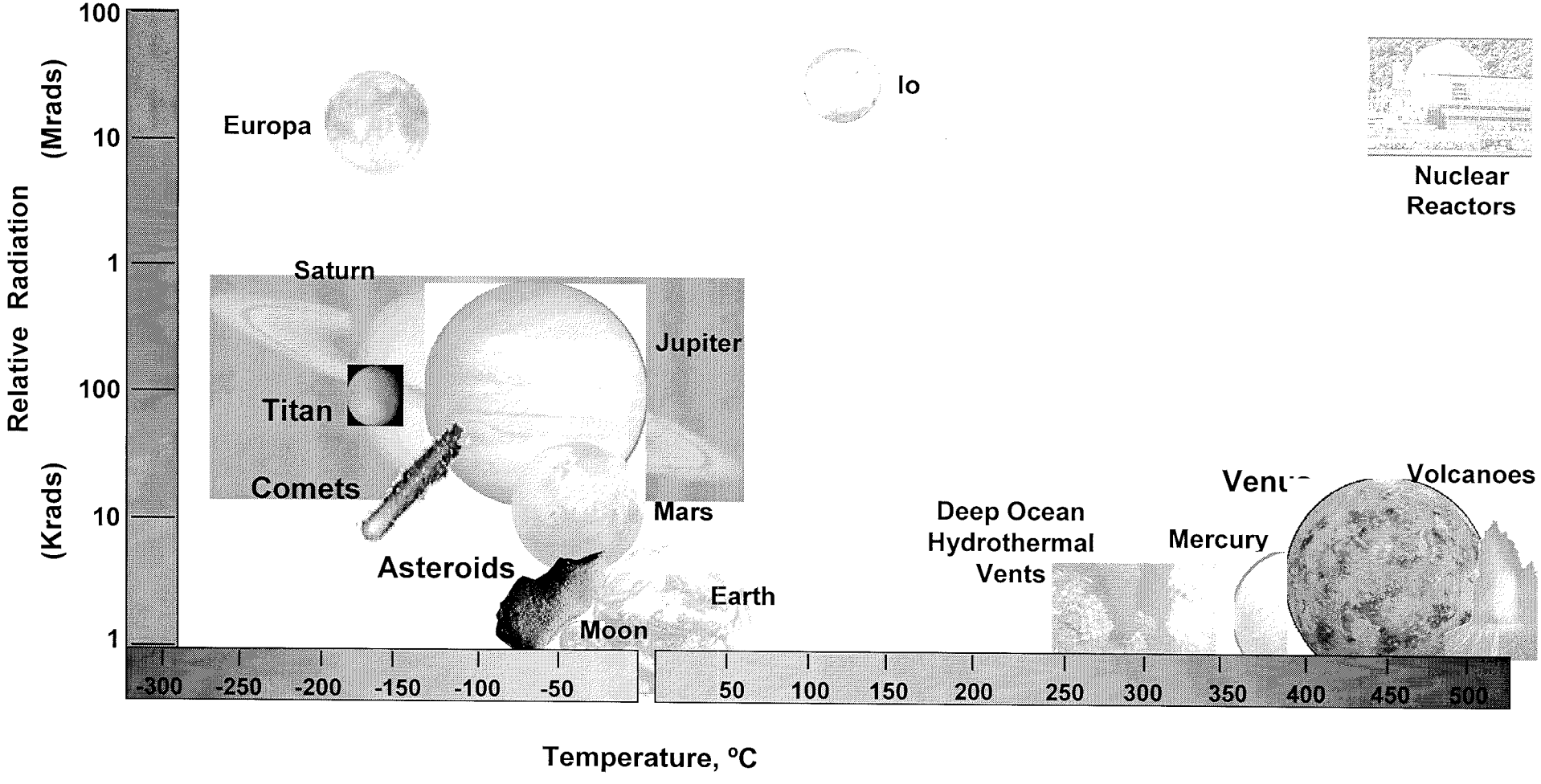
Planetary Extremes



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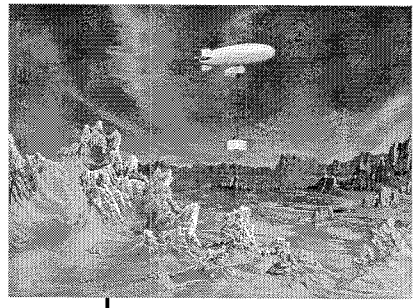
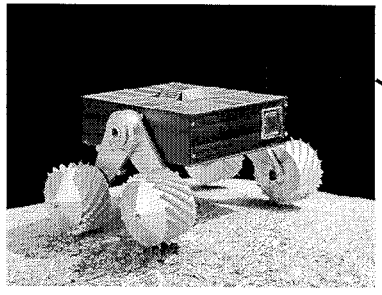
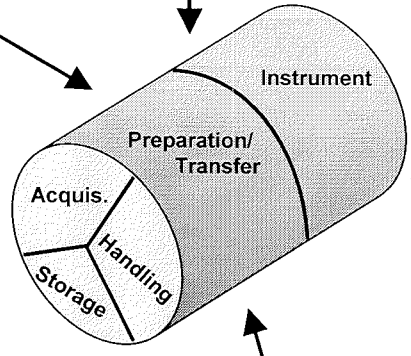
Generic Sample Acquisition/ Processing System



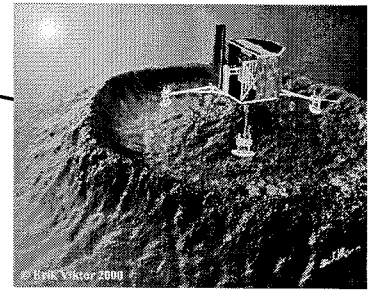
Titan Aerial Platform

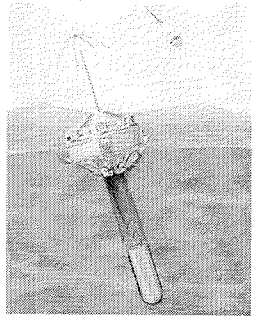


Asteroid Nanorover



Venus/Comet Lander





Titan Sonde

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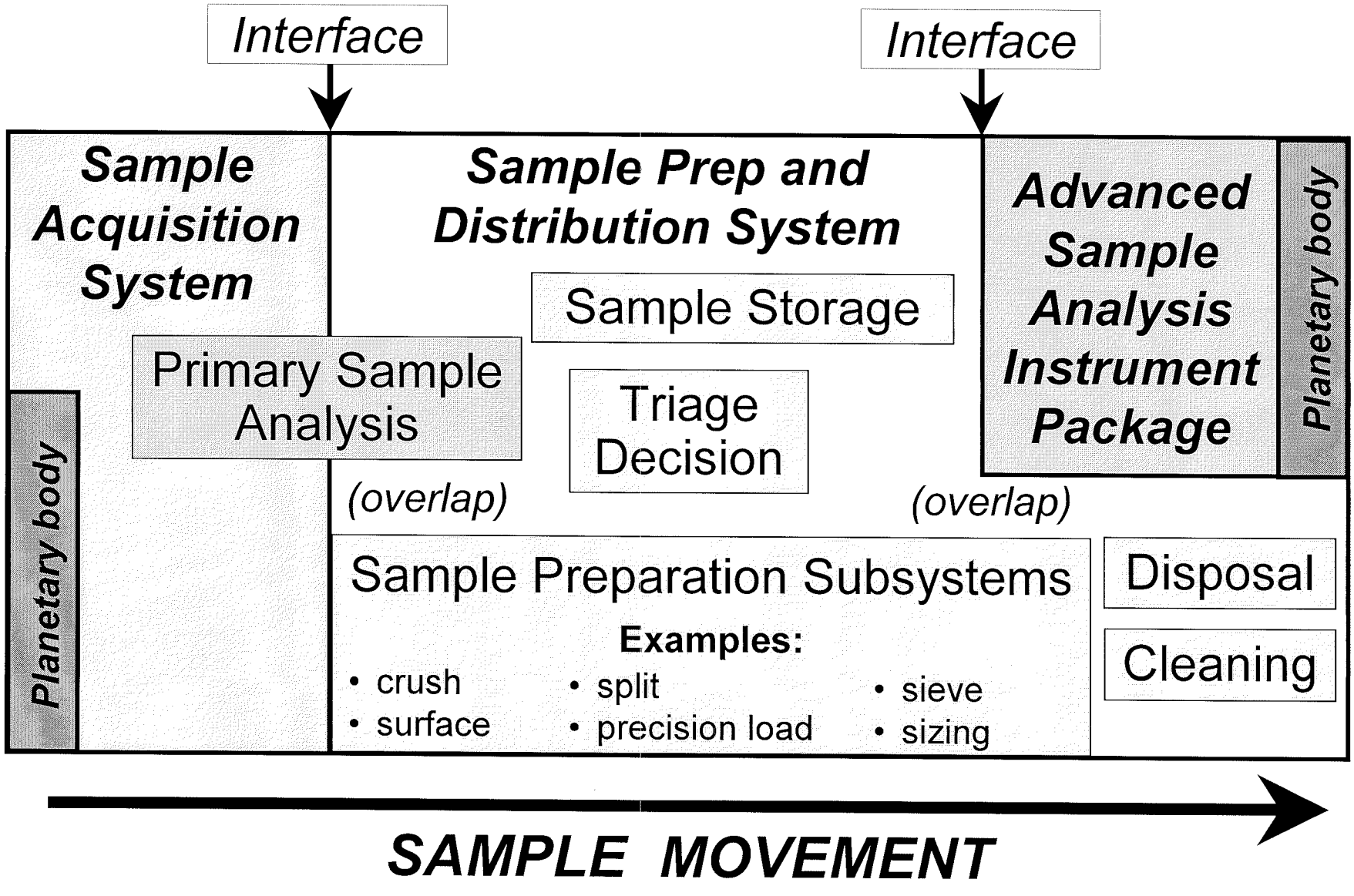
General Sample Acquisition/Processing System Relationships



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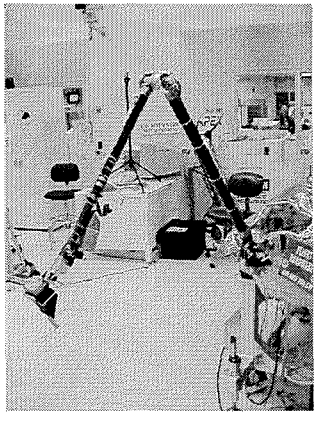
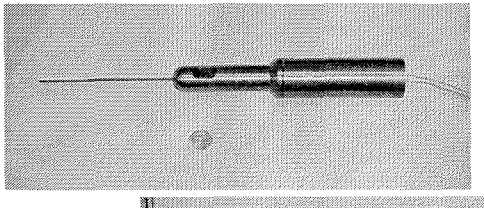
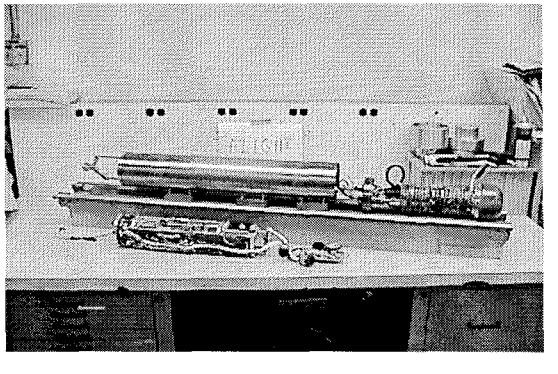
Sample Acquisition Technology: State-of-Art (SOA) Planetary Devices



- **Flight Sample Acquisition Devices**
  - **Robot arms** (Viking, SS RMS, MVACS'98, Mars'01)—operate at -45 °C with aid of heaters, CO_2/vacuum env, limited life
    None of these devices were ever designed to operate at Venus/Titan temp or pressure extremes
  - **Rovers** (nano-rover (no sampling), Mars'03 rover inst deployment—
    RA not designed to operate at Venus/Titan temp or pressure extremes
- **Prototype and/or Flight-Like Sample Acquisition Devices**
  - Honeybee Mars **rover auger**—operate at -45 °C with aid of heaters, Mars ambient atmos/press, 1/3 g, limited life—**no testing ever done at Venus/Titan temp extremes**)
  - Self tuning **ultra-sonic drill** (USD)—operate at Mars ambient conditions—some drilling has been done in the lab in -140 °C ice and 300 °C oven but with **limited success (i.e., system performed marginally)**
  - **Percussive penetrator**/Micro end-effector (MEE)
    (ESA BEAGLE with MEE micro-corer/sampling device has been tested at Mars ambient conditions—**no testing ever done at Venus/Titan temp extremes**)
  - JPL **deep percussive penetrator—**sample obtained by forward motion of penetrator (only lab-tested at Earth-ambient temps)
  - JPL **cryobot/sonde** sample obtained by wicking/passive ingestion of melt liquid (lab-tested/tested in Earth Analog environment (Arctic glacier)





Sample Handling/Processing Technology: SOA Planetary Devices (Mars-centric Only)

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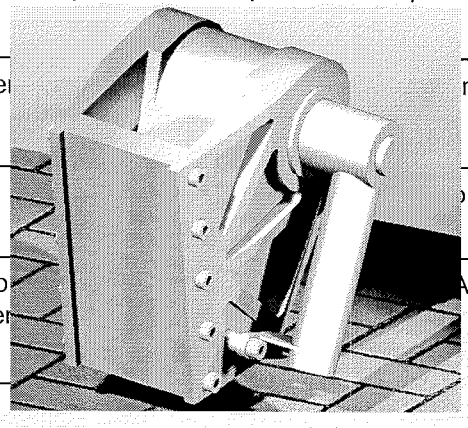
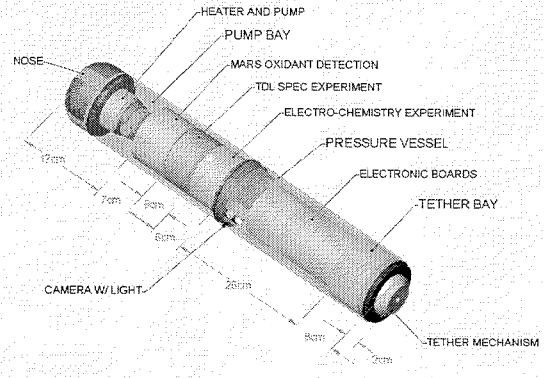
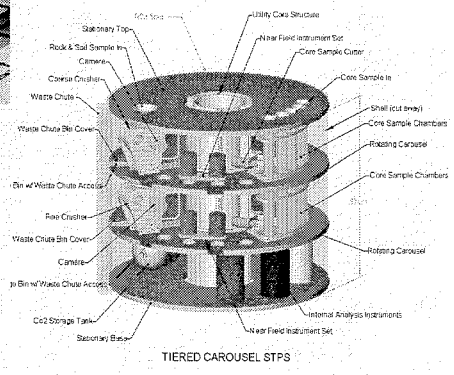
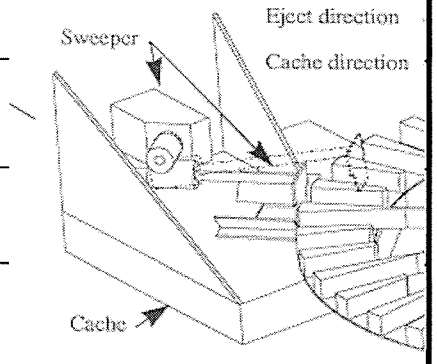
Mission / Device	Viking	MVACS 98	MSR03 Athena	MSR01 Lander	Comet/Rosetta	Mars Beagle-2	Mars Rock-hound	Mars IPSE
Launched	Yes	Yes	No	No	2003	2003	No	No
Lander or Rover	Lander	Lande			nder	Lander	Rover	Either
Crusher	No	No			)	No	Yes	No
RA End-Effector	Scoop, Sieve, Sensors	Scoop Came			A	Instruments	Clam Shell/ Scoop	Container, Micro-Motion Device
Carousel	No	N-					Yes	No
Sieving / Grinding	Sieve							
Sample Bins	No							
Storage	No				S	Yes		
Cleaning	Vibration				)	No	Sweep	No
Sample Processing Within Instrument	Soil heated in chamber	Soil heated in chamber/ volatiles examined	No	Microscope with wet chemistry mixing/μ-electrodes	Micro-vac-ovens process sample/ sample analyzed by mass spec	Micro-corer delivers sample to oven—sample heated/analyze volatiles	Sample analyzed by microscopic imager/APXS	Sample inserted into port—sample heated/ interrogated with UV spec





72cm CRYOBOT


TIERED CAROUSEL STPS



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SOA Planetary Sample Processing Devices (cont'd)

- **State of Planetary Sample Handling/Processing Technology**
  - All planetary sample processing has involved "dry" rock/soil samples—only MVACS'98 processed mixed ice/soil samples (perma-frost) at Mars ambient conditions—**no sample processing system has been designed specifically for sampling ice/liquid at near-cryogenic temps or for Venus/Titan environment extremes.**
  - Some design work has been done for Venus/CNSR sample delivery/storage but **little/no H/W development and testing has been done.**

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Benefits to Solar System Exploration Missions

- **In-situ sampling/analysis provides an opportunity to engage the public in experiencing the environment of Venus, a comet/asteroid, or Titan through surface/ subsurface images and data collected at the surface.**
- **Remote sensing platforms are limited** in ability to do detailed chemical/bio assays—**scientists need both remote sensing data and actual in-situ analysis** of surface/sub-surface material to get a true understanding of planetary/small body history and make-up.
- Age dating, stratigraphy, understanding heating/cooling cycles, volcanism (Venus)**, pristine chemistry are very difficult to do** at Venus/Titan/small bodies, unless in-situ samples are obtained and analyzed.

Technology Capabilities/Needs

- **Sample Acquisition Systems are Made Up of:**
  - Actuators
  - Bearings/seals
  - Links/joints
  - Sample entrapment devices [end-effectors, sampling tools (auger, corer)], liquid entrapment devices (capillaries, suction pumps)]
  - State assessment devices (sensors)
  - Power IF/cabling/connectors
  - Drive electronics/control system S/W (autonomy)
- **Sample Handling/Processing Systems are Made Up of:**
  - Sample receiving interfaces (ports, hoppers)
  - Sample preparation devices (crushers, sieves, filters, mixers)
  - Sample transport devices (robotic manipulation (carousels, pick-and-place), gas/liquid transport, charge coupled transport)
  - Sample processing devices (sizing, concentrating, reagent tagging, bio-tagging)
  - Sample contamination control (internal inst cleaning by mechanical means, chemical means, gas pressure means)
  - State assessment devices (sensors)
  - Power IF/cabling/connectors
  - Drive electronics/control system S/W (autonomy)

Are These Component Technologies Ready for the Extreme Heat/Cold of Either Venus or Titan?

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Technology Capabilities/Needs (cont'd)

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Extreme Environment Technologies

- **State of Venus Extreme Technologies**
  - **High temp actuators/bearings**—High-temp super-conductors, brushless motors, hard-magnetic materials allow ops up to 160 ºC. Ceramic alloys, self-lubricating materials (graphite alloys), chrome-oxide coatings provide bearing reliability in excess of Venus temps (600 ºC).
  - **High temp materials for sample acquis structures (links, coring tools, end-effectors)—**Ti/carbide and Ti/aluminide alloys provide limited life at Venus temps. Magnesium alloys provide low-mass, low-corrosion, high-strength, high-temp performance (300–400 ºC).
  - **Connectors/insulators**—High-temp ceramic or glass-mica composite connectors will survive Venus temps (~400 ºC) for limited periods of time. Si-ceramic insulators will remain intact up to 200 ºC.
- **Minimum Technology Needs Currently Not Addressed**
  - High-temp actuators (>200 °C)
  - High-temp insulators (>200 °C)
  - High-temp sensors/electronics (>200 °C) (see Extreme Electronics)
  - High-temp power source (batteries—see Extreme Electronics)
  - Autonomous high-temp integrated sampling/sample handling/instrument package (never done)
  - Hot rock/sediment sample storage/processing (never considered)

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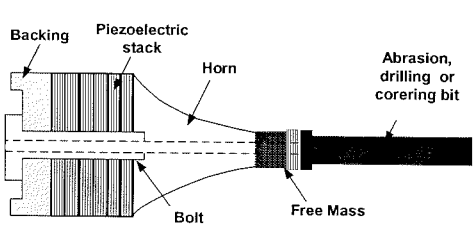
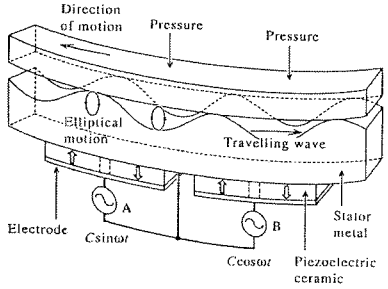
Technology Capabilities/Needs (cont'd) Extreme Environment Technologies

- **State of Small Bodies/Titan Extreme Technologies**
  - **Cryo-actuators/bearings**—Cryo-actuators exist for use in industry vacuum/cryo-chambers (10^{-7} Torr/liqH_2) using low-expansion alloys like Nickel-Chromium steel, AlNiCo magnets, and synthetic Moly-based thin film or dry lubricants.
  - **Cryo-materials for structures**—Materials like Ti-alloys, graphite composites will provide sufficient life for sampling in cold environments.
  - **Cryo-connectors/insulators**—Micro-hermetic/vacuum space qualified connectors already exist that will not fatigue at temps of 100K. Si-hybrid insulators over enamel film have reasonable fracture life at cryo-temps.
- **Minimum Technology Needs Not Currently Addressed**
  - Cryo-sensors/electronics (< -200 ºC) (see Extreme Electronics)
  - Cold energy storage devices other than RPS (batteries/ultra-capacitors < -65 °C—see Extreme Electronics)
  - Autonomous cryo-integrated sampling/sample processing/instrument package (never done)
  - Autonomous cryo-sample movement/storage (never done)

Technology Development Plan/Roadmap: Strategy and Methodology

Extreme Temperature Actuators/Insulators





Hot (°C/High Pressure (100 Atm)

400

200

-100

-200

Cold (°C/Low Pressure (0-2 Atm)

SOA

04

06

08

10

2008—Develop Advanced High-Temp Actuators:
- Ceramic piezo actuators (400–600 °C)
- Shape memory actuators (400 °C)
- Advanced phase-change materials (hydrated salts/ closed-loop evaporative cooling/heat transfer micro-structures (possibly driven by mini-RPS))

2005—Develop Hybrid System Components:
- High temp super conductors
- Brushless motor configurations
- Hard-magnetic materials
- Phase-change materials (Li-hybrids)
- Shape memory actuators (>200 °C)

2004—Model/Experiment:
- Characterize material changes at > 200 °C
- Identify advanced high-temp. materials
- Identify insulating/phase-change materials

2004—Test SOA at Titan/Small Body Components:
- NiCr actuators
- AlNiCo magnets
- Molybdenum-based dry lubes
- Si-hybrid enamel film wire/junction coatings

2006—Refine SOA Technology as Required for Cold Bodies

Technology Development Plan/Roadmap: Strategy and Methodology

Extreme Temperature Sample Acquisition Systems

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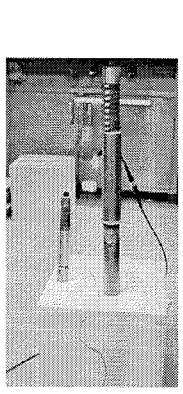
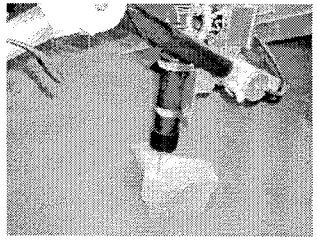




2008—Design/Develop/Test Extreme drill/USD:
- High temp drill materials/ceramic piezo actuators
- Shape memory orientation controls/core control
- Advanced phase-change materials for cooling (if needed)

2005—Test Hybrid Performance:
- Maximum survival period
- Reliability assessment
- Decision made on performance gaps/segregation of H/W (cold/hot regions)

2004—Design/Develop Hybrid USD System:
- High-temp drill/USD with piezo materials
- Lander deployment device
- Position/orientation control actuators
- High-temp coring tool with shape memory position control/ core removal
- Phase-change cooling system

Hot (°C/High Pressure (100 Atm)

400

200

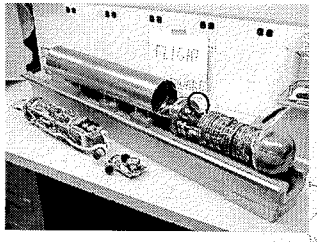
SOA | 04 | 06 | 08 | 10

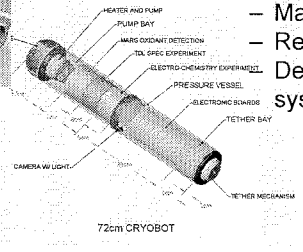
-100

-200

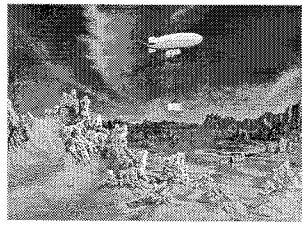
Cold (°C/Low Pressure (0-2 Atm)

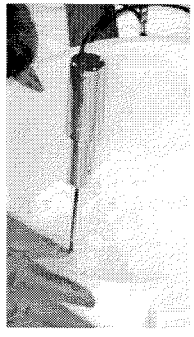
2004—Design/Develop:
- Low-temp melting sonde
- Low-temp auger/USD/percussive penetrator
- Deployment device for lander/rover/ aero-platform





72cm CRYOBOT





2005—Test Performance in Ice/Rock/ N2/Vacuum:
- Maximum survival period
- Reliability assessment
- Decision made on performance gaps/likely sampling system configuration for each environment

2008—Demo Extreme Systems:
- Ice penetrator (comet/Titan)
- Rock penetrator (asteroid)

Technology Development Plan/Roadmap: Strategy and Methodology

Extreme Temperature Sample Processing/Transfer Systems

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Hot (°C/High Pressure (100 Atm)

400

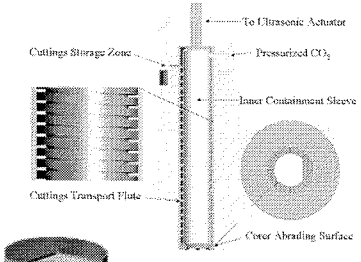
200

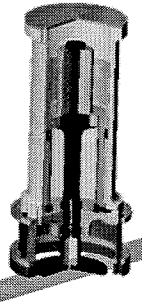
-100

-200

Cold (°C/Low Pressure (0-2 Atm)

Sample Type:
- Cores
- Fines

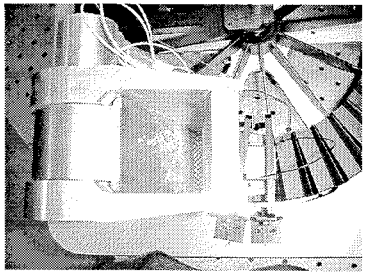




2008—Integrate/Test System:
- Reduce 0.5-cm particulate to 20-μ fines
- Reduce sample temp. by factor of 5
- Separate/transfer 10-g hot sample to instrument suite
- Move sample from 100 A to vacuum chamber (pressure control)

2005—Develop/Demo:
- Solids transfer to sample holding/ processing chamber
- Solids processing (micro-crush, core manipulation)
- Move sample to instrument, e.g.
  - Electro-static grids
  - MEMS
  - Doped micro-fluidics
  - Gas streaming

2004—Model/Experiment:
- Detailed heat transfer/dynamic model (from sample acquisition to sample processing)
- Analysis of pressure environment
- End-to-end sample processing chain simulation (sample flow model)



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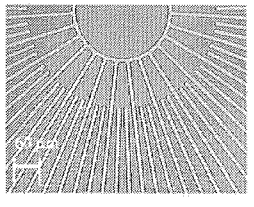
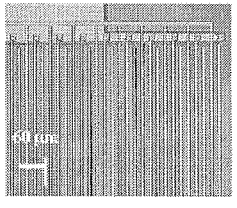
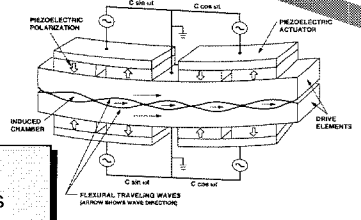
2004—Model/Experiment:
- State/phase-change equations
- Effects of pressure/high organics
- End-to-end sample processing chain





2005—Develop/Demo:
- Control of solids/volatiles in vacuum
- Phase-change control/pressure control
- Iso-thermal sample transfer
- Move sample to instrument, e.g.
  - micro-capillary systems
  - peristaltic pumps
  - piezo pumps/valves
  - osmotic pumps



2008—Integrate/Test System:
- Transfer cryo-temp. organic-rich fluid to instrument (0.1 cc – 100 cc)
- Transfer fluid sample from 2 A to vacuum chamber
- Transfer ice/liquid sample 100m in micro-capillary umbilical to instrument chamber

Sample Type:
- Unconsolidated cores
- Ice impregnated with dust
- Liquid (water/organics)

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Technology Development Plan/Roadmap: Strategy and Methodology

Contamination Control Systems

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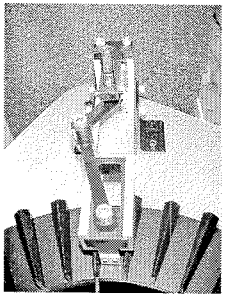

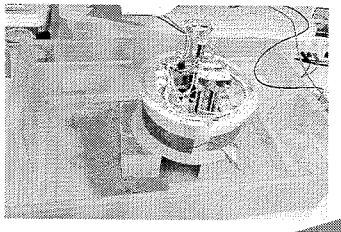

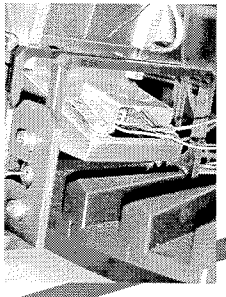

Hot (°C/High Pressure (100 Atm)

400

200

-100

-200

Cold (°C/Low Pressure (0-2 Atm)

Sample Type:
- Solids

Sample Type:
- Ice w. dust
- Liquids (H20/organics)

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2008—Develop/Demo 0.1% by Weight Control:
- End-to-end contamination control sub-system
- Single chamber sample processing/ cleaning

2005—Develop/Demo 0.5% by Weight Contamination Control
- Hybrid MEMS/ultrasonics/vib
- Gas jetting
- Mechanical (brush/mat'l coatings)
- Multiple chambers vs. single chamber

2004—Characterize/Test:
- Particulate adhesion dynamics
- Effects of high temperature
- Mechanical/gas cleaning (e.g., ultrasonic/ vib/gas jet)

2004—Characterize/Model/Test:
- Surface adsorption dynamics
- Decontamination strategies
  - UV
  - Dilution by multiple purges
  - Progressive filtering

2005—Develop/Demo 0.5% by Weight Control:
- UV /filtering
- Dilution cycling
- Multiple chambers vs. single chamber

2008—Develop/Demo 0.1% by Weight Control:
- End-to-end hybrid contamination control system
- Single chamber sample processing/ cleaning

JPL

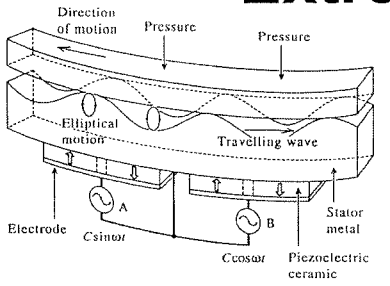
Technology Products/Drivers Summary

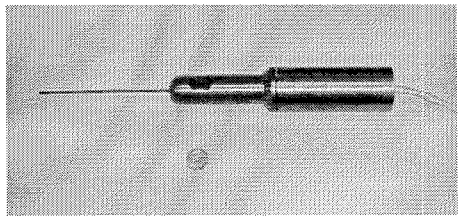
CISSR Team In-Situ

Technology Product	Technology Drivers
Model thermal/dynamic processes (thermal fatigue, phase change, surface adsorption)	Required to understand how materials/samples behave under extreme environmental conditions
Design/develop high temp actuators/ insulators	Must develop actuators/insulators which will operate at >200 °C
Sample acquisition/delivery systems	Must design/develop sampling technology that will function in extreme environments and meet severe mass/volume/power constraints
Sample processing---expose fresh surface	Required by majority of analytical instruments
Sample processing---sample volumetric splitting	Required by sample processing system to move controlled amounts of sample (by volume/mass) to different instruments
Sample processing---sieving, filtering	Required by many analytical instruments to control sample grain size and/or sample quality
Sample processing---fine grind	10–100 μm requested by some instruments (mass spec)
Sample processing---sample storage/retrieval	Requires system feature for maximizing potential science by allowing multiple instrument interrogation of same sample/sample portions
Sample handling---precision transfer/manipulation	Required to enable transfer of sample from planetary surface to pressure/temp-controlled storage chamber and instrument interrogation chambers
Acquisition/process monitoring and automation	Required to accommodate comm delays/real-time fault management
Contamination control	Required by analytical instruments to reduce cross-contamination between samples and prevent distortion of data

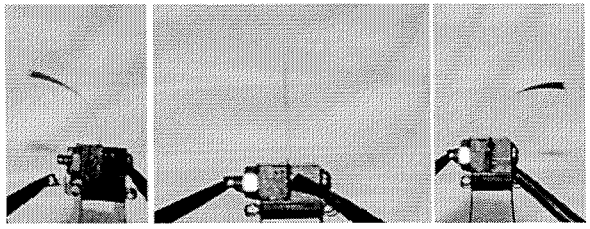
Key Products/Milestones: Extreme Temperature Actuators/Insulators

Team In-Situ





Micro-piezo actuator design can be used for rotary/percussive actuation



Shape memory actuators for moving material and/or providing positional control of acquisition devices

Objectives:

Develop extreme actuation/insulation technologies to enable control of sample acquisition devices and sample transfer/processing devices at either hot ambient conditions and/or with minimal additional temperature control subsystems (e.g., phase change). Significant consideration must be given to minimizing mass/volume.

Products:

- Prototype actuators which operate at > 460 °C or < -200 °C
- Characterization of component failure modes/life and whether additional thermal control required

Tasks:

Extreme Heat

- Investigate/characterize actuator/insulator material changes that effect operation at >>200 °C
- Identify new materials and/or required cooling strategies to keep material in stable regime
- Develop lab experiments to confirm models and test limits of material/cooling hybrid system

Extreme Cold

- Test SOA actuators/insulators to confirm performance—test limitations at -200 °C

Funding Profile ($M):

FY'04	FY'05-'07	FY'07-'09
0.5M	1M	1M

Milestones to TRL 6:

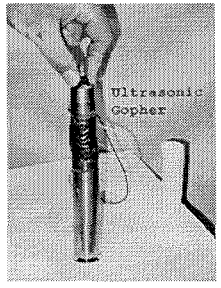
FY'04: Investigation/lab test advanced actuator designs/materials and cooling materials (phase change)

FY'05–'07—Design/fabricate prototype actuators/ insulators and test in controlled lab environment

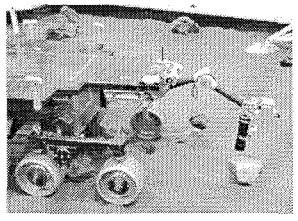
FY'07–'09—Develop/demo complete actuator/temp control system for hot/cold environments

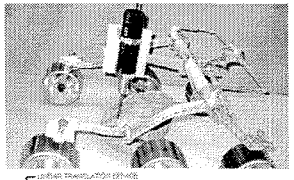
Key Products/Milestones: Sample Acquisition/Delivery Systems

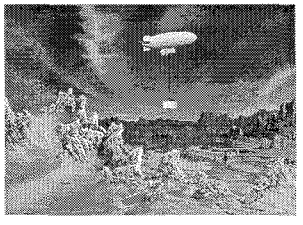
Team In-Situ

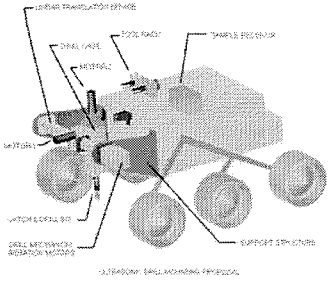


Ultra-sonic tethered penetrator

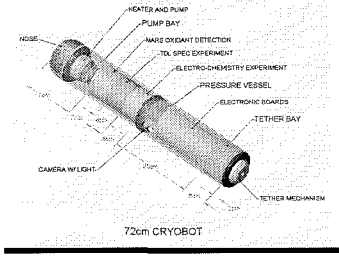








Ultra-sonic drill mounted on rover



Cryobot/sonde showing three instruments in wet/ pump bay with internal sample delivery wicking system

Objectives:

Develop sample acquisition designs/prototypes. Effort includes use of extreme actuator/insulator technology, design/development of sampling prototypes (mechanical + electronics/S/W control).

Products:

- Prototype sample acquisition/delivery H/W and S/W
- Demo of sample acquisition/delivery to instruments
- Test of system performance/reliability at extreme temperatures

Tasks:

- Investigate sample acquisition concepts for Venus/cold bodies, e.g.:
  - Ultra-sonic drills/mechanical augers
  - Percussive penetrator/Melting sonde with micro-wicking (shallow penetration ~10's cm)
- Determine likely configurations that meet flight volume/mass/power constraints
- Design/develop prototype systems (H/W and S/W)
- Validate system performance in simulated extreme environments

Funding Profile ($M):

FY'04	FY'05-'07	FY'07-'09
0.7M	3M	5M

Milestones to TRL 6:

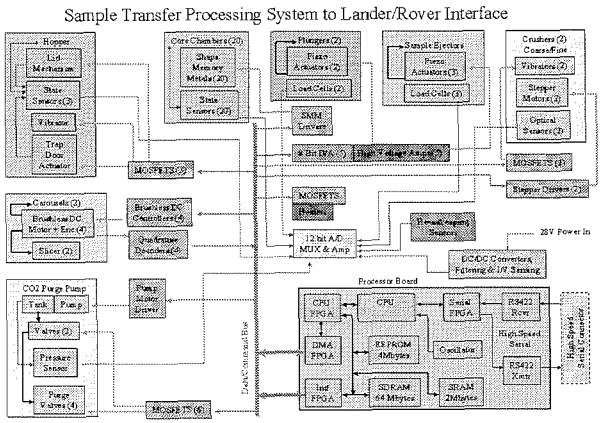
FY'04—System designs for hot/cold environments

FY'05–'07—Develop/test system components in extreme environments

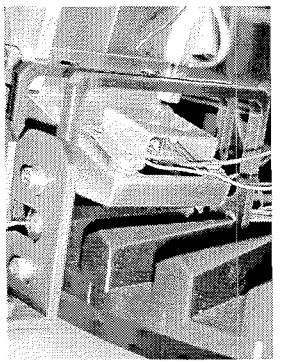
FY'07–'09—Demo prototype integrated system with strawman instrument suite

Key Products/Milestones: Sample Processing Architecture Design/Development

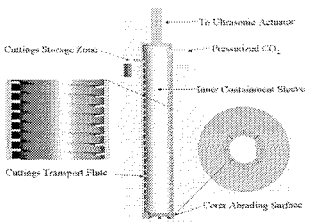
Team In-Situ



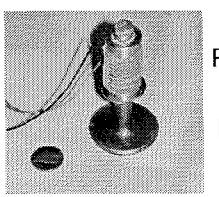
JPL Sample Processing Control Architecture



Mini-crusher vibration/sieve sample sizing/splitting unit



Core/cuttings removal and storage



Piezo-driven surface prep device

Objectives:

Develop and demonstrate architectures for sample processing and distribution. Effort includes design to strawman instrument sample type/ physical properties (core, fines, ice/liquid), aero-platform/ rover/lander interface design, automation and process monitoring/control.

Products:

- Sample process/prep designs
- Interface designs with possible instrument payloads and acquisition platforms
- Prototype sample processing system

Tasks:

- Mechanical design considering example instrument sample needs
- Aero-platform/rover/lander sample acquisition interface design
- Electronic control system design
- S/W architecture design (process monitoring, automation, failure analysis/fault recovery)
- Test/demonstration of sample processing system:
  - Core removal, crushing/sieving with sample splitting
  - Staged pressure/temp control
  - Ice/liquid/dust separation, filtering, sample splitting

Funding Profile ($M):

FY'04	FY'05-'07	FY'07-'09
0.5M	1.5M	3M

Milestones to TRL 6:

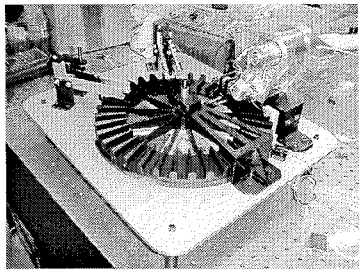
FY'04—System design concepts

FY'05–'07—Develop/demo/test sample processing technology components including press/temp control

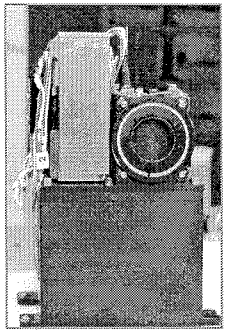
FY'07–'09—Test/demo integrated sample acquisition processing system

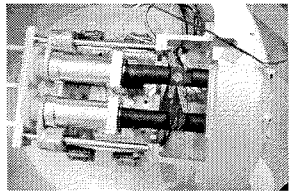
Key Products/Milestones: Sample Movement/Storage

Team In-Situ

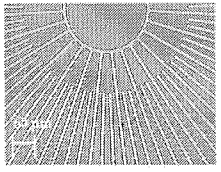


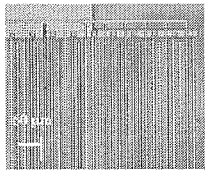
Rock/soil crusher and sample wheel distribution/storage system



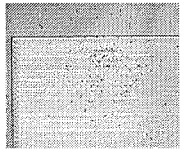


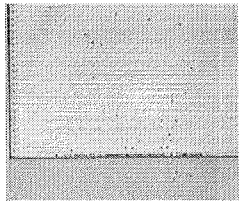
MECA micro-wet chemistry sample injection/ mixing cells





Micro-fluidic circular and linear fluid transfer traces





Ultra-sonic grid showing particles redistributed evenly

Objectives:

Develop, test, and evaluate system concepts for movement of samples to and from sample processing stations, instruments and storage containers.

Products:

- Design of hot/cold sample transfer system
- Develop/test sample transfer system options
- Integrate/test/demo sample prep + sample transfer system

Tasks:

- Mechanical gravity flow/controlled sample retention or disbursement and portioning (cores/fines/ ice-dust/liquid)
- Sample storage (storage of splits, pressure/temp control of sample in holding chamber)
- Motion and control (sample presentation to instruments included)
- Controlled sample manipulation/sieving to move select sample volume/particulate size
- Core/ice sample separation or filtering
- Prototype/BB system development/demo

Funding Profile ($M):

FY'04	FY'05-'07	FY'07-'09
0.7M	2M	4M

Milestones to TRL 6:

FY'04—Lab test sample transfer mechanisms to establish best options for solids/ice/liquid, e.g.:

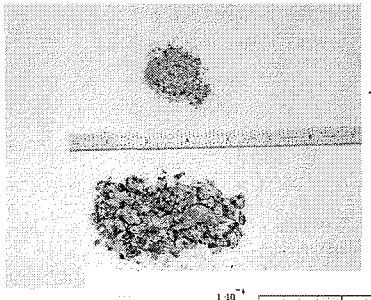
- MEMS/nano-optical bench
- Electrostatic grids/ultrasonics
- Piezo-pumps
- Micro-fluids/doped particle carriers

FY'05–'07—Design/develop sample transfer components including sample storage

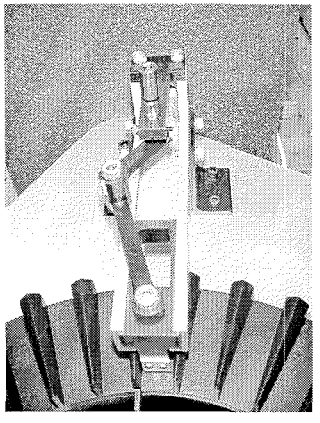
FY'07–'09—Test/demo sample transfer and storage system for solids/liquids

Key Products/Milestones: Cross Contamination Control/Cleanout

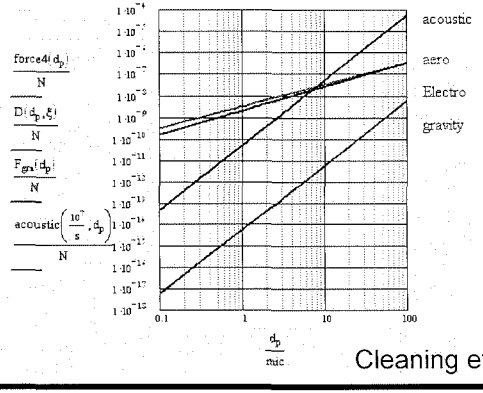
Team In-Situ



Typical core/fines processed



Sweeper system with anti-static coating on sample wheel



Cleaning effectiveness plots

Objectives:

Develop, test, and evaluate system concepts for controlling cross contamination to better than 0.5% (eventual goal of 0.1%). Effort will include mechanical means, anti-static coatings, gas jetting or flushing.

Products:

- Results of contamination control modeling and determination of most effective processes
- Demonstration of contamination control technologies in controlled lab environment

Tasks:

- Model effectiveness of mechanical (vib/brush), gas/liquid jetting, surface coatings
- Verification of particle adherence characteristics (charge and size distribution) in lab
- Ultrasonic vibration efficacy as enhancement to mechanical cleaning
- Antistatic coatings on non-conducting surfaces
- Design/test of gas jetting/dilution/flushing strategies

Funding Profile ($M):

FY'04	FY'05-'07	FY'07-'09
1M	2M	2M

Milestones to TRL 5–6:

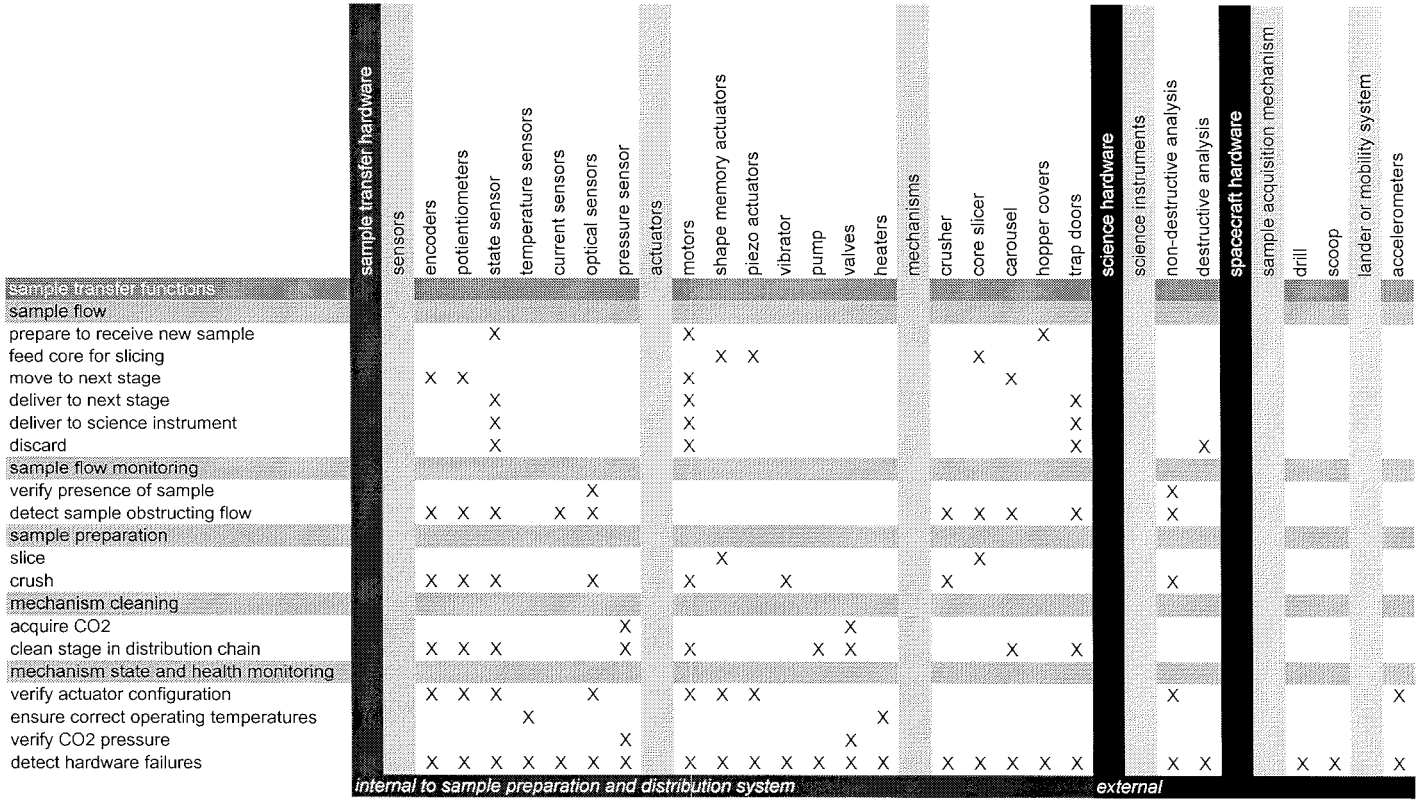
FY'04—Complete modeling of particle adherence/ adsorption dynamics

FY'05–'07—Develop/test bench-top contamination control strategies

FY'07–'09—Demonstrate capability/issues with reaching 0.5% by weight and 0.1% by weight contamination goals

Technology Development Plan/Roadmap:

Function to Hardware Mapping—Relationship Between Sample Acquisition/Processing Control System and Autonomous S/W Function Performed (Example)



Timeline: SOA → '04–'06 → '07–'10

Derive system state eqs. Develop/test S/W models Integrate/demo prototype

Note: This technology cuts across all sample acquisition/processing/contamination control subsystems and its associated cost is incorporated into each subsystem funding profile.