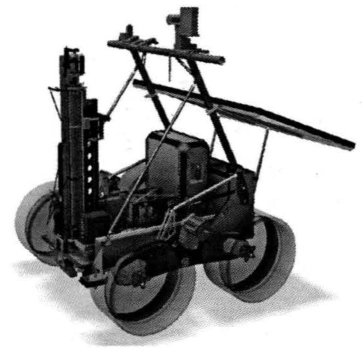
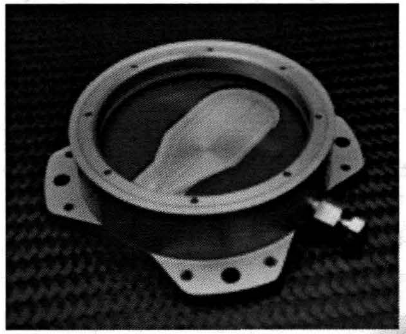
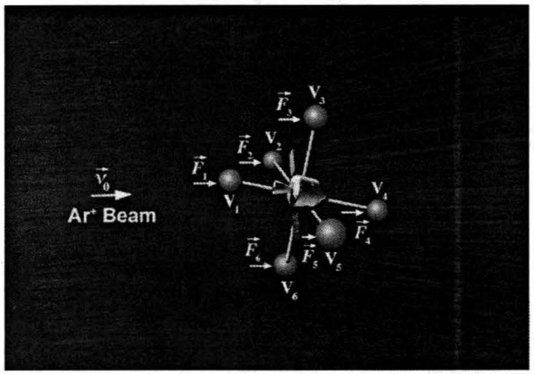
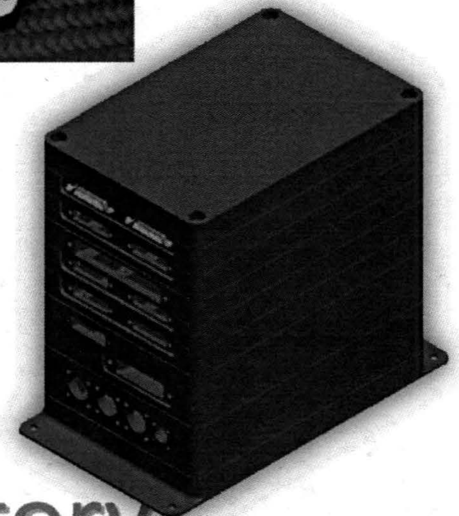
Recent Projects in the KSC Applied Physics Lab



Stanley Starr
Branch Chief





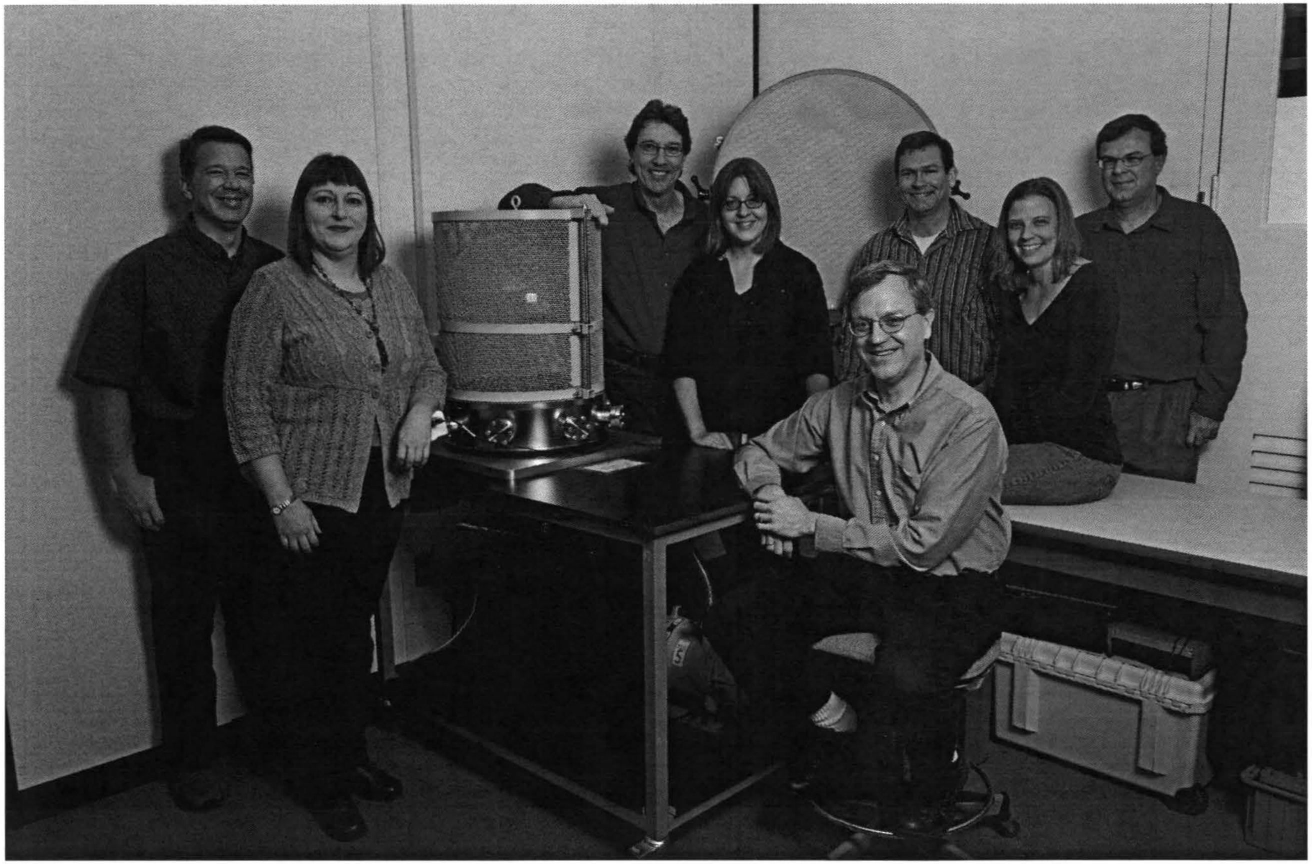


Presentation for the

Space Life Sciences Laboratory

August 19, 2013

The KSC Applied Physics Lab

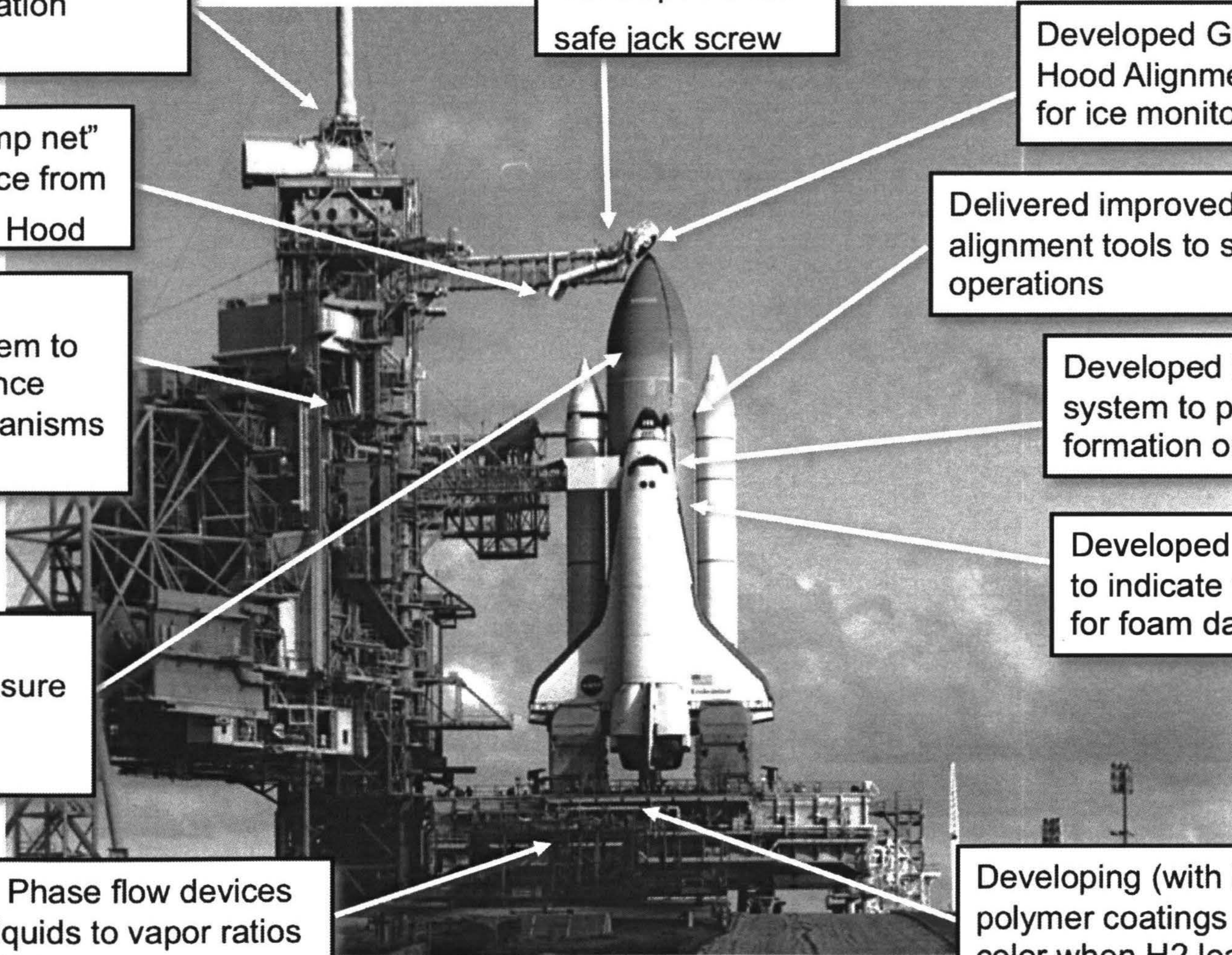


From L to R:
Tom Moss
Teresa Lawhorn
Stan Starr
Ellen Arens
Bob Youngquist
Curtis Ihlefeld
Janine Captain
Mark Nurge
Mary Coan (not shown)

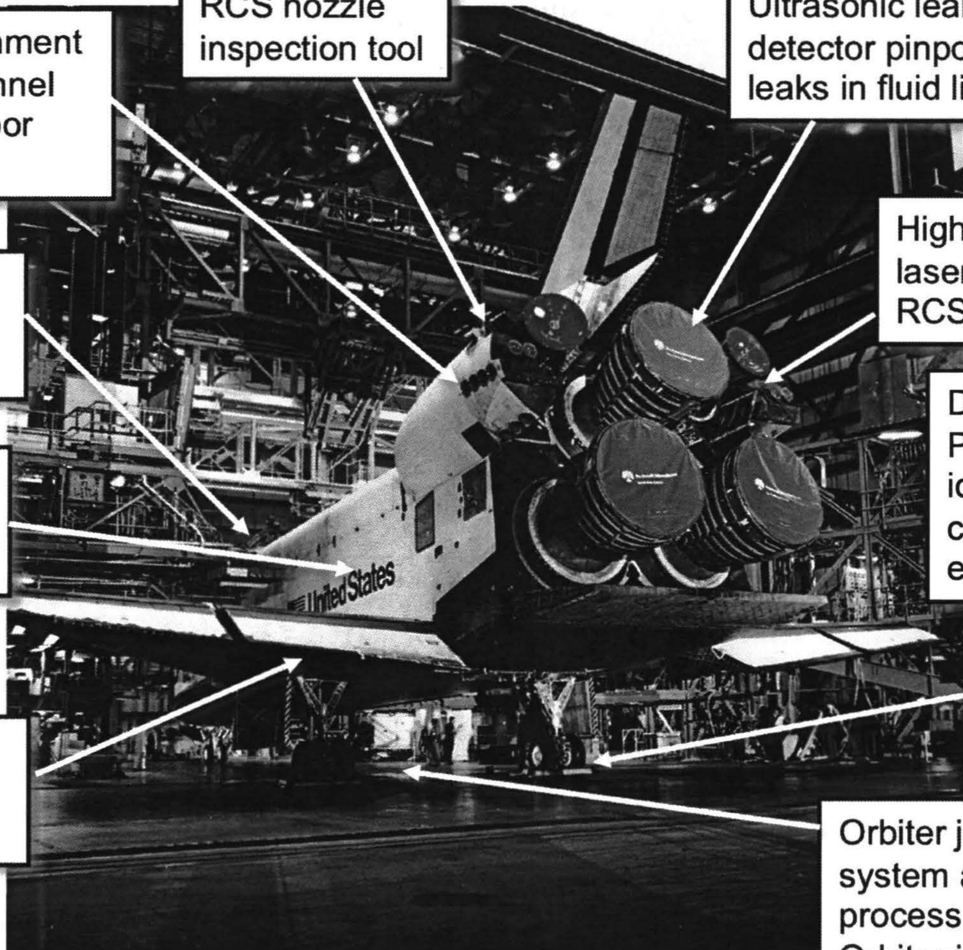
Agenda

- Shuttle heritage
- ISRU /RESOLVE
  - Payload for Lunar Lander/Rover on Polar Areas of Moon
  - Avionics/Software
- New Technologies for Exploration
  - Radiation Shielding work
  - Cooperative Tractor Beams
- Questions?

Vehicle and Launch Pad Projects



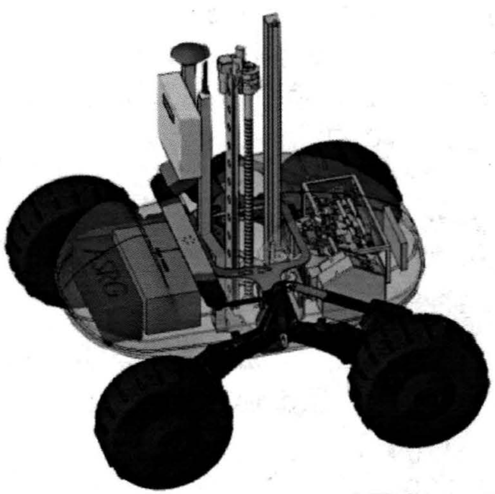
Orbiter Processing Facility (OPF) Projects

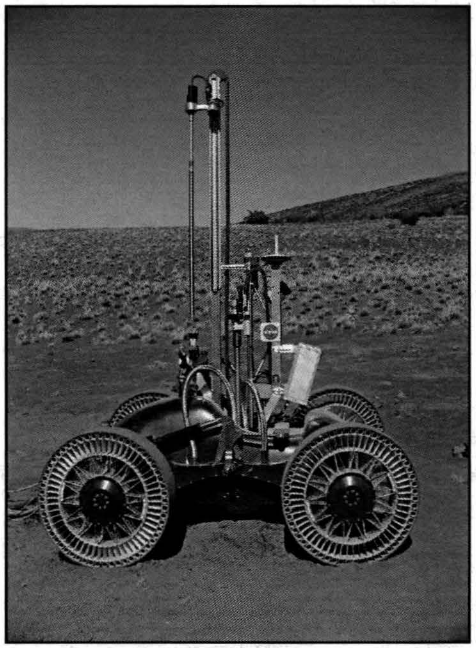


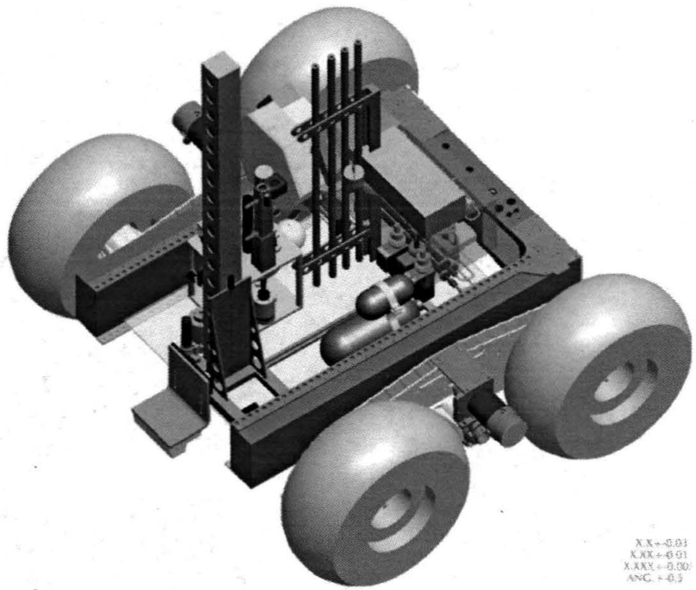
*RESOLVE**

- **RESOLVE is an internationally developed payload that is intended to prospect for resources on other planetary bodies. Part of the <u>Resource Prospector</u> mission.**

- **RESOLVE is a miniature drilling and chemistry plant packaged onto a medium-sized rover to collect and analyze soil for volatile components such as water or hydrogen that could be used in human exploration efforts.**

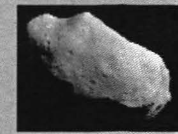






*Regolith & Environment Science and Oxygen & Lunar Volatile Extraction

In-Situ Space Resources



Four major resources on the Moon:

- **Regolith**: oxides and metals
  - Ilmenite 15%
  - Pyroxene 50%
  - Olivine 15%
  - Anorthite 20%
- Solar wind volatiles in regolith
  - Hydrogen 50 – 150 ppm
  - Helium 3 – 50 ppm
  - Carbon 100 – 150 ppm
- **Water/ice** and other volatiles in polar shadowed craters
  - 1-10% (LCROSS)
  - Thick ice (SAR)

Three major resources on Mars:

- **Atmosphere**:
  - 95.5% Carbon dioxide,
  - 2.7% Nitrogen,
  - 1.6% Argon
- **Water in soil**: concentration dependant on location
  - 2% to dirty ice at poles
- Oxides and metals in the soil

Water

is the Key:

Life Support

Rocket Propellant

Radiation Shielding

~85% of Meteorites are Chondrites

Ordinary Chondrites 87%

FeO:Si = 0.1 to 0.5

Fe:Si = 0.5 to 0.8

Pyroxene

Olivine

Plagioclase

Diopside

Metallic Fe-Ni alloy

Trioilite - FeS

Source metals (Carbonyl)

Carbonaceous Chondrites 8%

Highly oxidized w/ little or no free metal

Abundant volatiles: up to 20% bound water and 6% organic material

Source of water/volatiles

Enstatite Chondrites 5%

Highly reduced; silicates contain almost no FeO

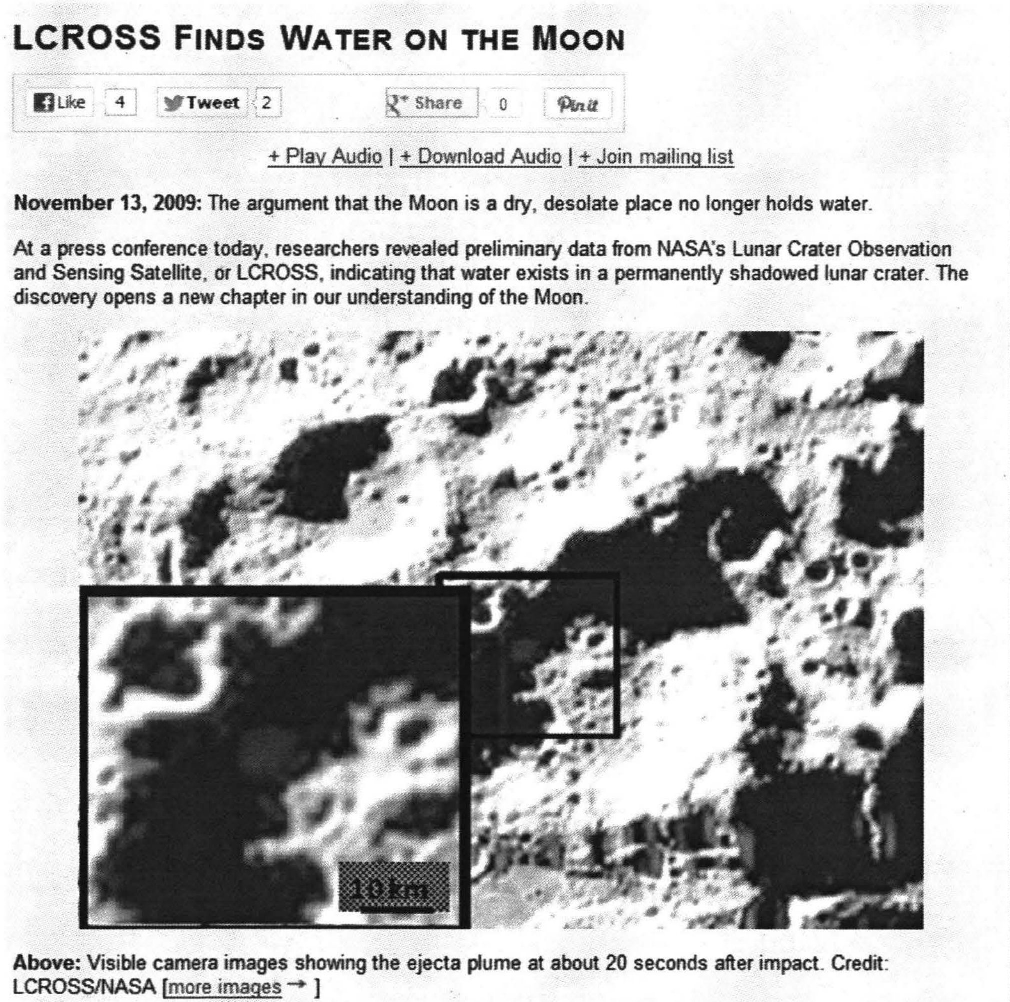
60 to 80% silicates; Enstatite & Na-rich plagioclase

20 to 25% Fe-Ni

Cr, Mn, and Ti are found as minor constituents

Easy source of oxygen (Carbothermal)

Back in 2009…



LCROSS Finds Water on the Moon

Like 4 | Tweet 2 | Share 0 | Pin it

+ Play Audio | + Download Audio | + Join mailing list

November 13, 2009: The argument that the Moon is a dry, desolate place no longer holds water.

At a press conference today, researchers revealed preliminary data from NASA's Lunar Crater Observation and Sensing Satellite, or LCROSS, indicating that water exists in a permanently shadowed lunar crater. The discovery opens a new chapter in our understanding of the Moon.

10 km

Above: Visible camera images showing the ejecta plume at about 20 seconds after impact. Credit: LCROSS/NASA [more images →]

RESOLVE Mission Options – Mission Fundamentals

Primary Mission:

✓ **Verify the existence of and characterize the constituents and distribution of water and other volatiles in lunar polar surface materials**

- **Map the surface distribution of hydrogen rich materials** (Neutron Spectrometer, Near-IR Spectrometer)
- **Extract core sample from selected sites** (Drill Subsystem)
  - to a depth of 1m with minimal loss of volatiles
- **Heat multiple samples from each core to drive off volatiles for analysis** (OVEN Subsystem)
  - from 100K to 150°C
  - from 0 up to 100 psia (reliably seal in aggressively abrasive lunar environment)
- **Determine the constituents and quantities of the volatiles extracted** (LAVA Subsystem)
  - Hope to find and quantify H_2, He, CO, CO_2, CH_4, H_2O, N_2, NH_3, H_2S, SO_2
  - Survive limited exposure to HF, HCl, and Hg

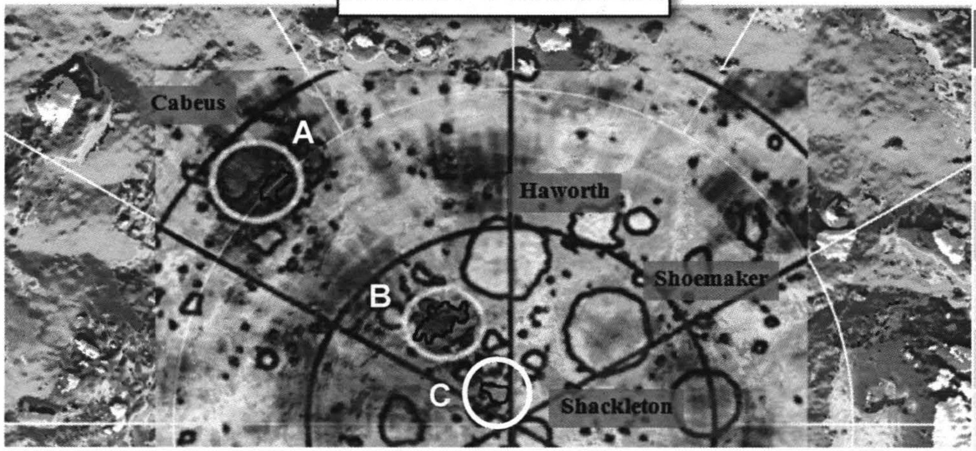
Secondary Mission:

✓ **Demonstrate the ISRU Hydrogen Reduction Process to extract oxygen from lunar regolith**

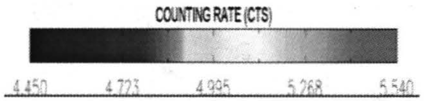
- **Heat sample to reaction temperature** (OVEN Subsystem)
  - from 150°C to 900°C
- **Flow H_2 through regolith to extract oxygen in the form of water** (OVEN Subsystem)
- **Capture, quantify, and display the water generated** (LAVA Subsystem)

RESOLVE Mission Options – Potential South Pole Landing Sites

LEND Results



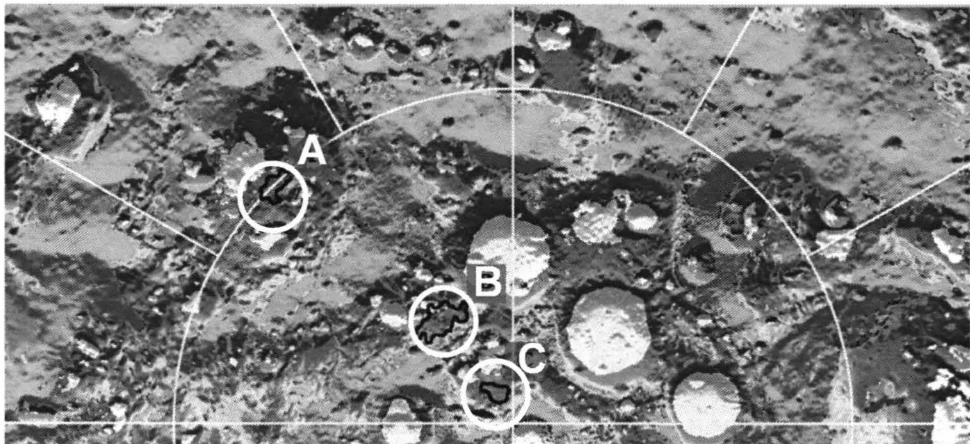
LEND Data (circa Fall 2009)



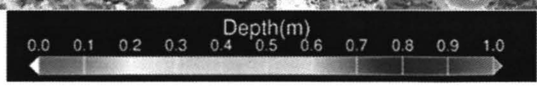
Site Analysis

Site:	A	B	C
Shallow "Frost Line"	<0.1 m	<0.2 m	<0.1 m
Slopes	<10°	<15°	<10°
Neutron Depletion	4.5 cps	4.7 cps	4.9 cps
Temporary Sun*	4 days	2-4 days	5-7 d
Comm Line of Sight*	8 days	17 days	17 days

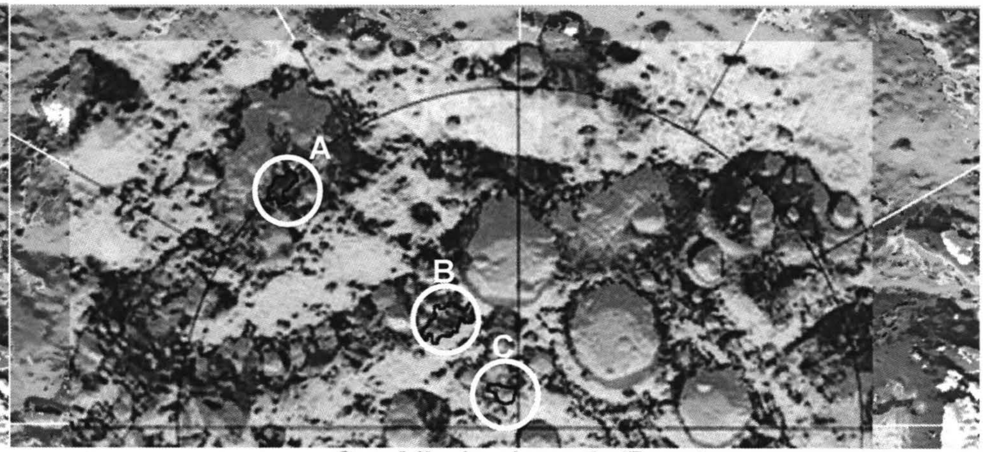
* may not coincide



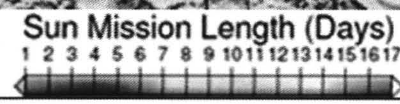
Depth to where water loss is < 1 kg m^{-2} per Gyr



Predicted Volatile Stability



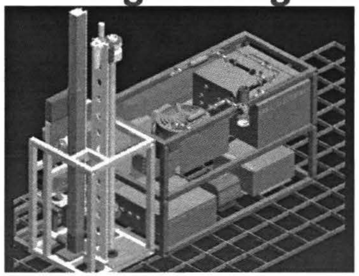
Solar illumination for May 2017

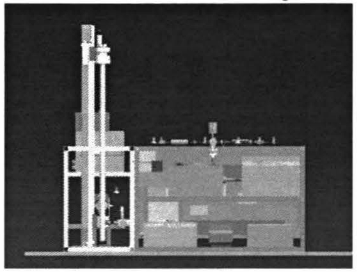


Solar Power Potential

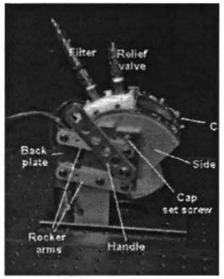
RESOLVE Development Background - Building on the Past

Engineering Breadboard Unit #1 (2007)

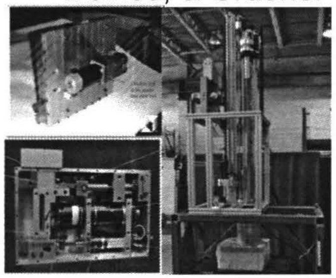




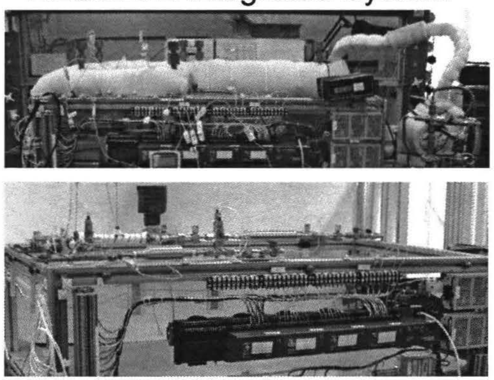
Volatile Reactor



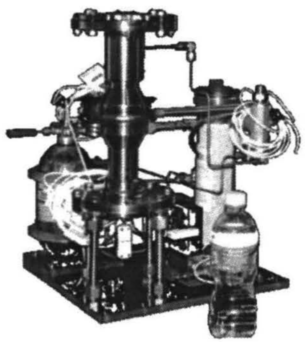
Drill, Sample Metering Device, & Crusher



RESOLVE Integrated System

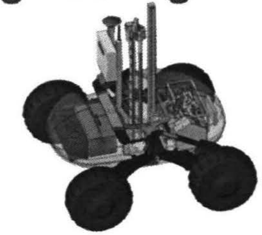


O_2 Production Demo

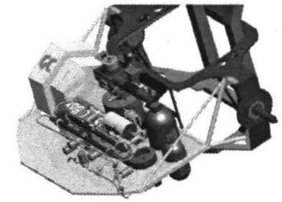


Large laboratory scale, proof of concept HW

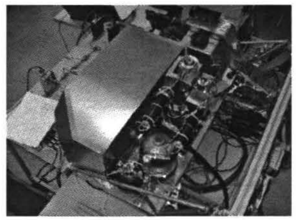
Engineering Breadboard Unit #2 (2008/2010)

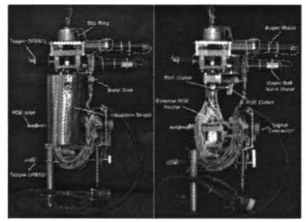


Combined Sample Metering & Crusher Unit



Integration onto Scarab

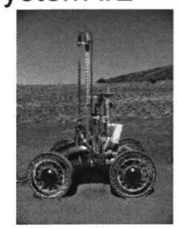


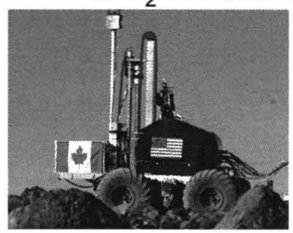


RESOLVE Integrated System #2

Combined Volatile Reactor & O_2 Production Demo

Field Tested thrice at Analog site in Hawaii (2008, 2010)



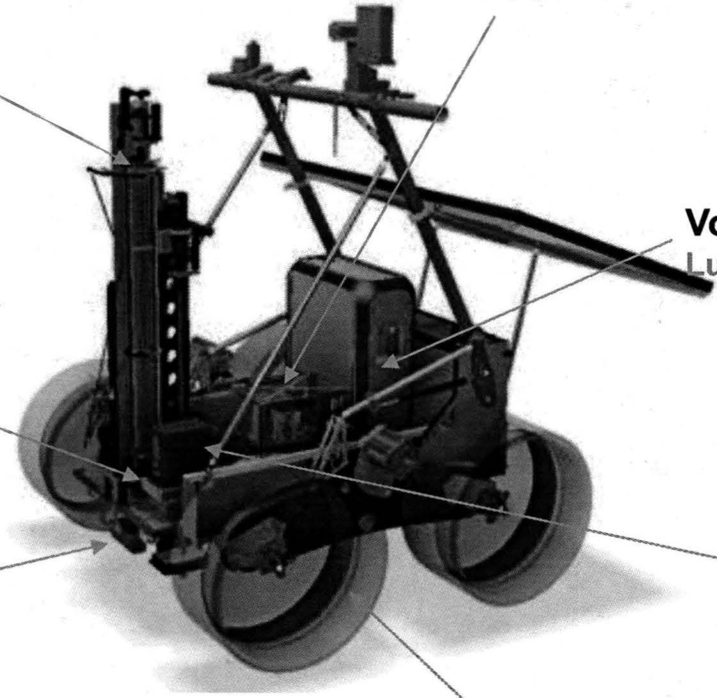


Moderate scale, mobile COTS based HW

RESOLVE (Regolith & Environment Science and Oxygen and Lunar Volatile Extraction)

Sample Acquisition –
Auger/Core Drill [CSA provided]

Volatile Content/Oxygen Extraction –
Oxygen & Volatile Extraction Node (OVEN)



Volatile Content Evaluation –
Lunar Advanced Volatile Analysis (LAVA)

Sample Evaluation –
Near Infrared Spectrometer (NIR)

Resource Localization –
Neutron Spectrometer (NS)

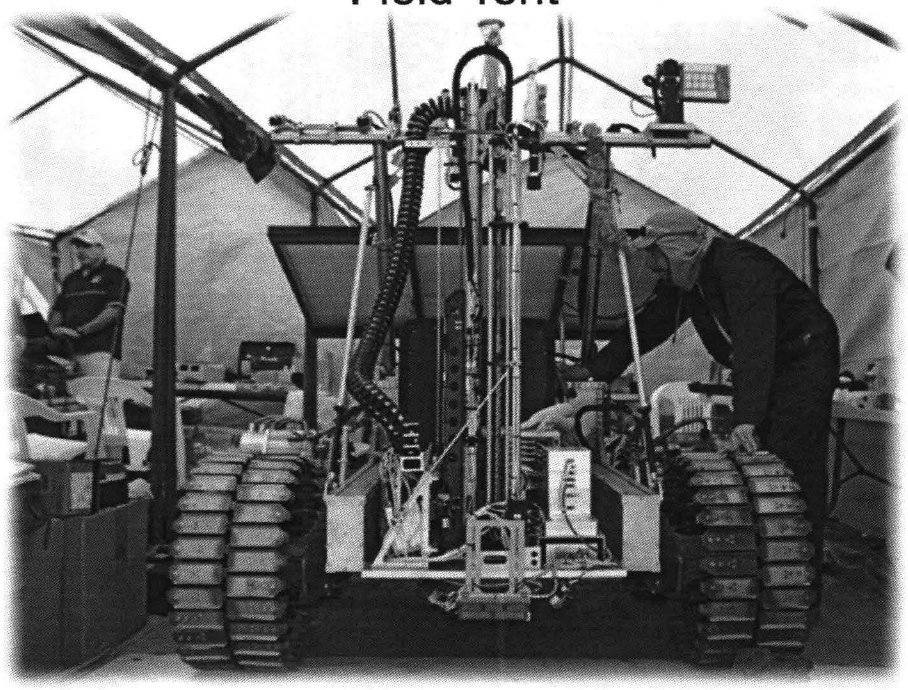
Operation Control –
Flight Avionics [CSA/NASA]

Rover

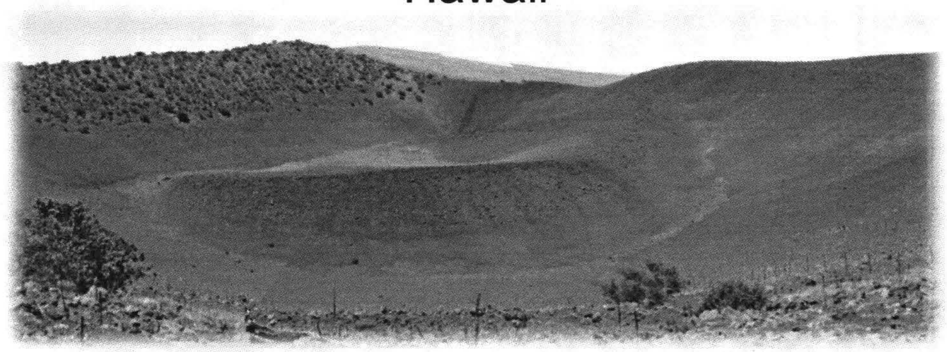
RESOLVE Instrument Suite Specifications
- Nom. Mission Life = 10+ Cores, 12+ days
- Mass = 60-70 kg
- Dimensions = w/o rover: 68.5 x 112 x 1200 cm
- Ave. Power; 200 W

RESOLVE Field Testing 2012

Field Tent



Hawaii



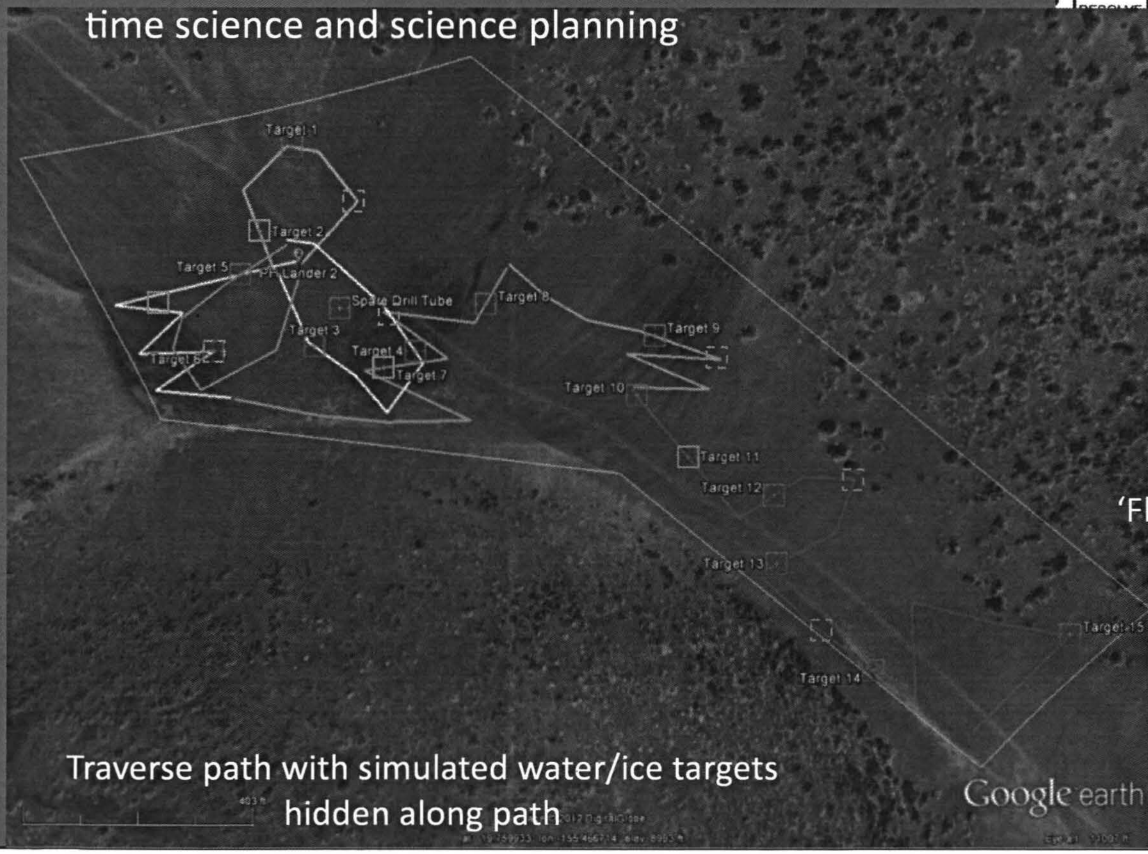
Roving

Hawaii

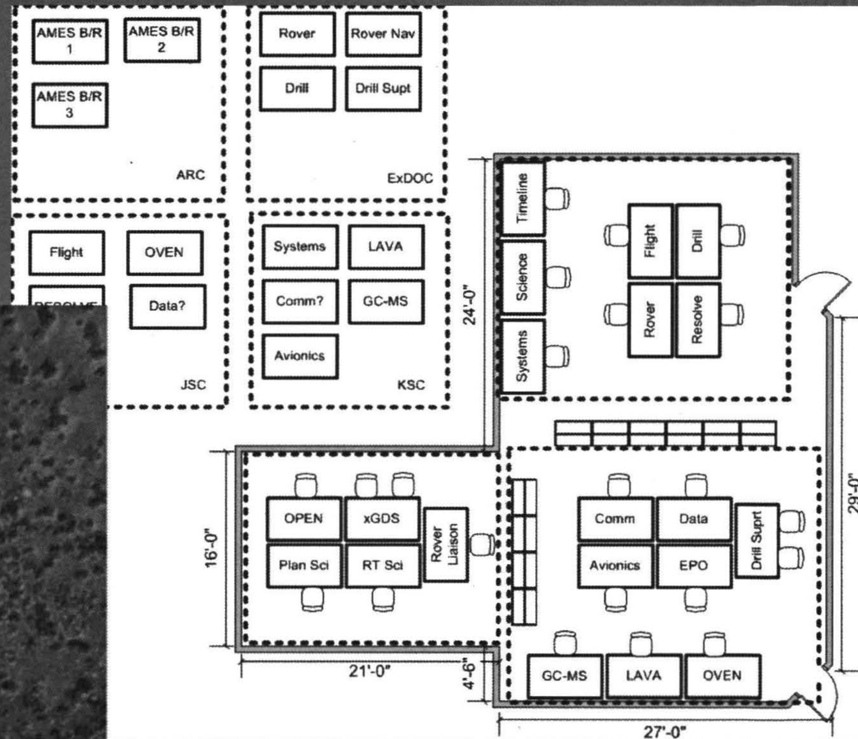

1. Lander to safely arrive on Moon's surface
3. Solar power for energy
6. Instrument for detecting water
4. Drill to pull up lunar soil
5. Reactor for heating up soil and "boiling" off water and chemicals
2. Rover for traversing the Moon

Lunar Polar Resource Mission Simulation

- All RESOLVE & rover operations initially controlled by ops center in Hale Pohaku
- Rover control transitioned to ExDOC at CSA HQ
- Sample processing operations transitioned to KSC/JSC at end of test day in Hawaii
- ARC science room to support both real-time science and science planning



Traverse path with simulated water/ice targets hidden along path



'Flight control' rooms in Hawaii, Houston, Kennedy, and Montreal. Science room at Ames

2013 RESOLVE Risk Reduction Phase

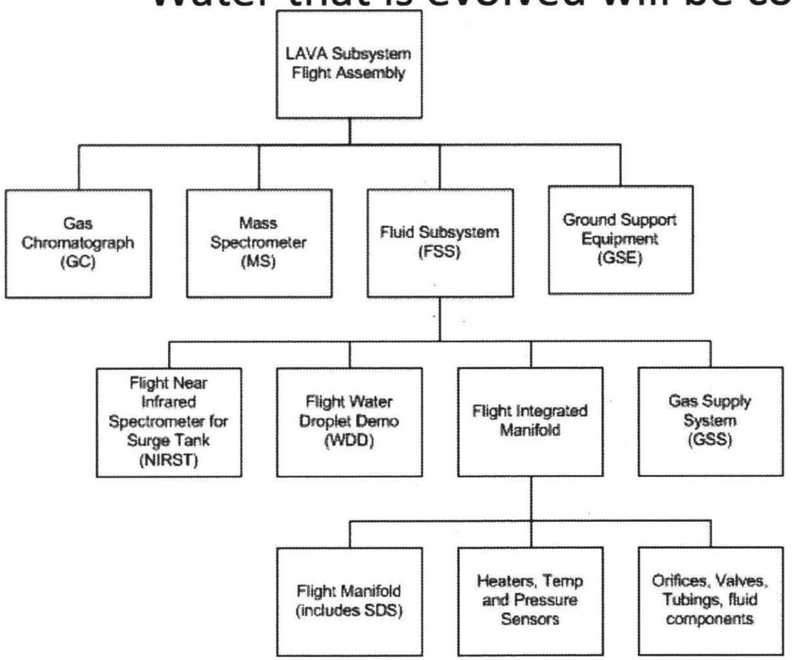
Prior to Mission Concept Review (MCR) & Authority to Proceed (ATP) for the Resource Prospector Mission (RPM), in preparation for flight development, the RESOLVE payload subsystems have been directed to address risks as part of a risk reduction phase

Three RESOLVE payload subsystems are led by the Applied Physics Lab:

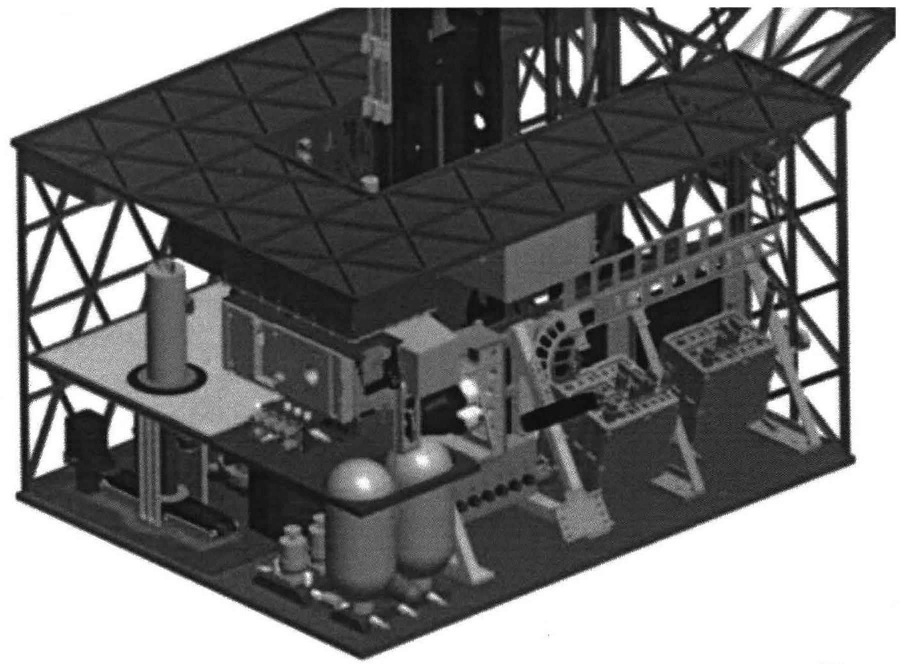
- LAVA Instrument: PI Dr. Janine Captain
- Avionics: Subsystems Lead: Curtis Ihlefeld
- Software Subsystem Lead: Tom Moss

LAVA Overview

- LAVA subsystem is one of the instruments of the RESOLVE payload.
  - Gases evolved by OVEN from regolith samples will be identified and quantified by LAVA.
  - Gases of interest are H_2O, CO, CO_2, H_2, H_2S, NH_3, SO_2, C_2H_4.
  - Water that is evolved will be condensed and photographed.

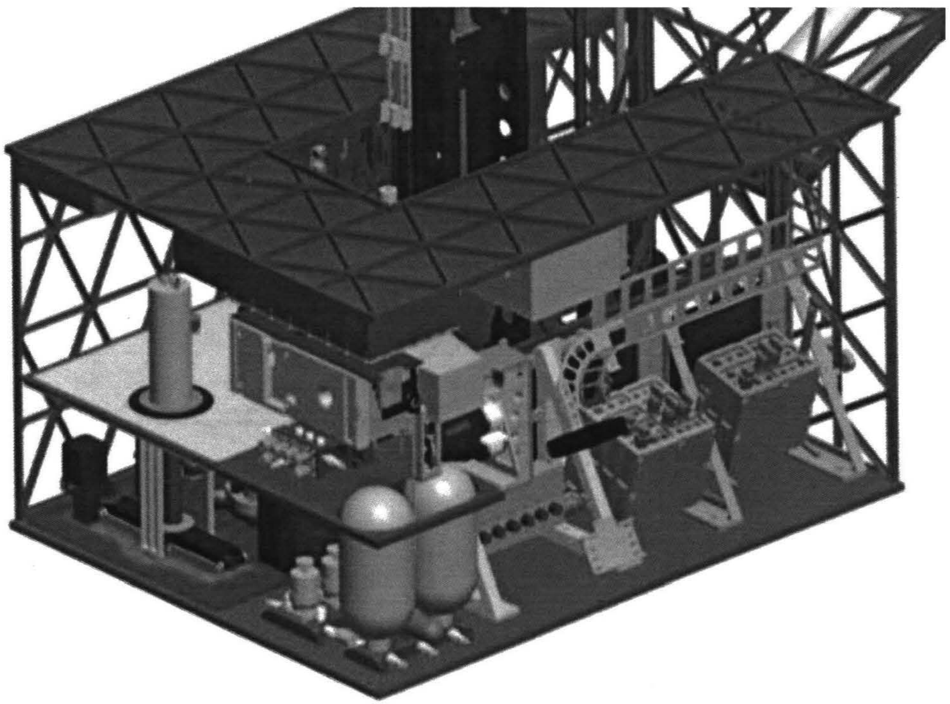


LAVA Physical Architecture - Flight

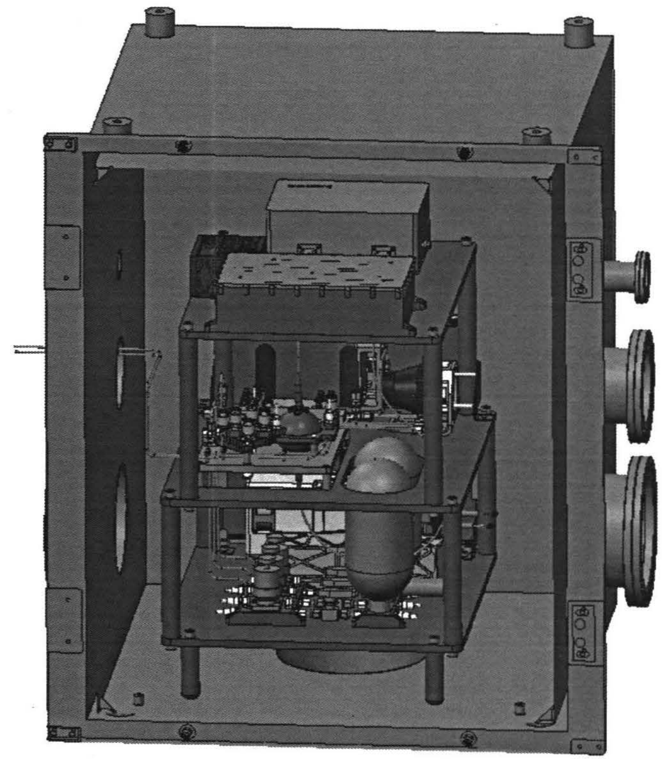


LAVA Vacuum Testing

- Simplified Structure to fit in Test Vacuum Chamber
  - Components located similar to flight to simulate tubing lengths
  - FSS & SDS mounted to insulated plate and covered with MLI

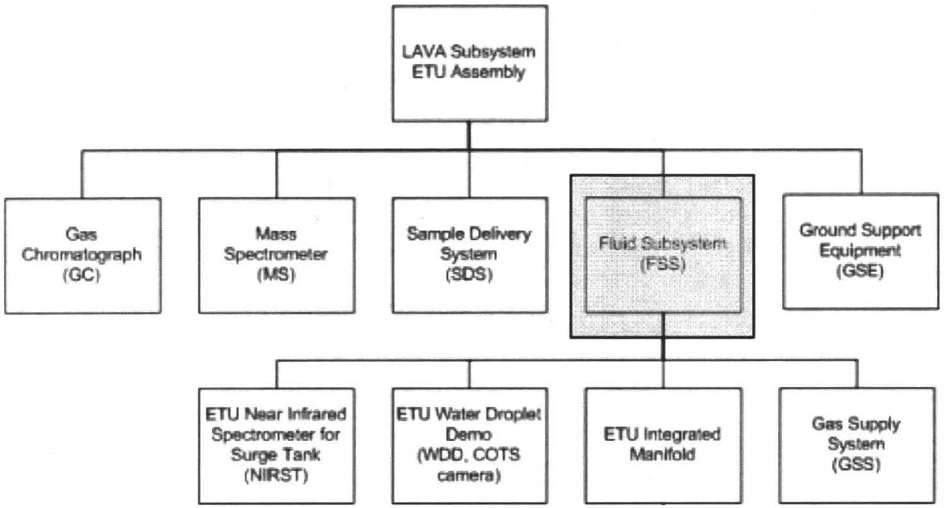


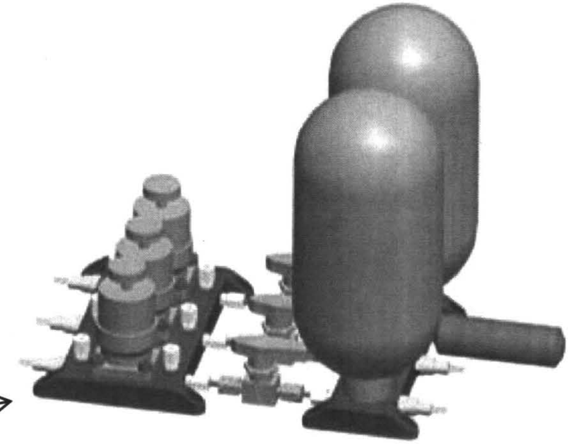
LAVA Flight Model

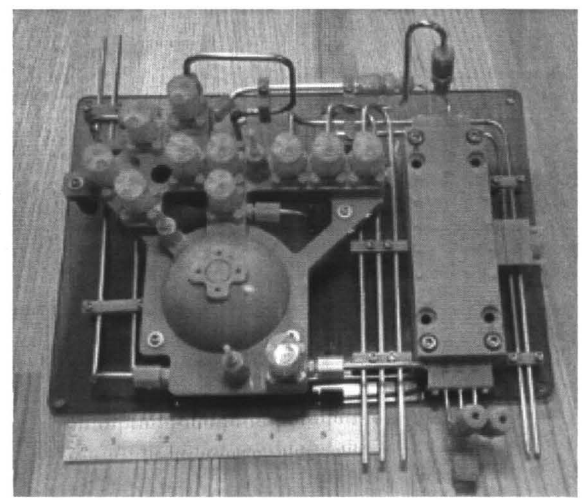


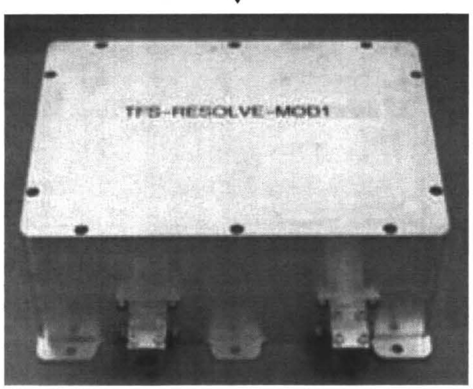
LAVA ETU Model

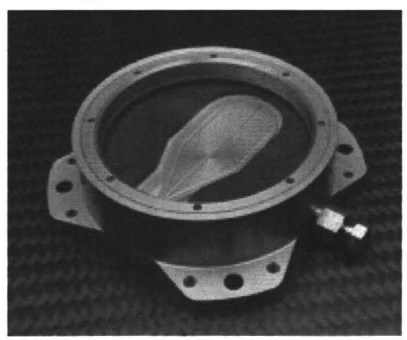
LAVA Fluid Subsystem - ETU





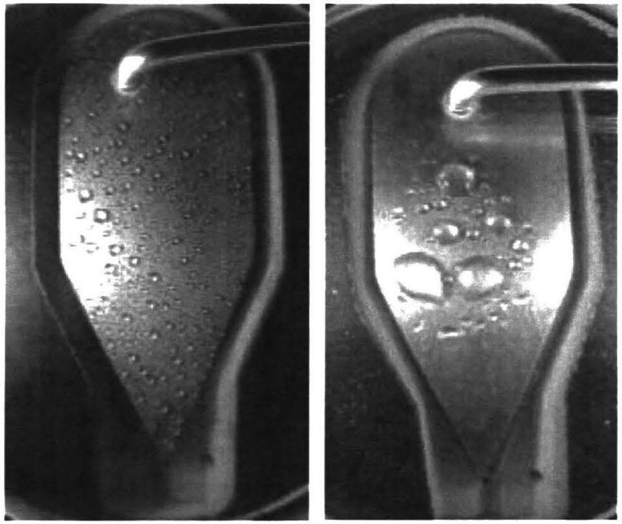


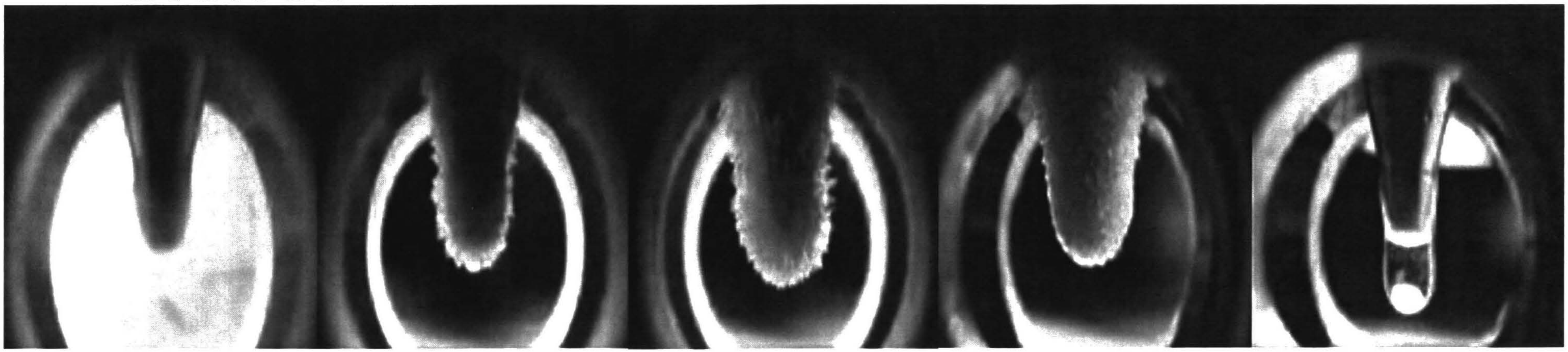




WDD Overview

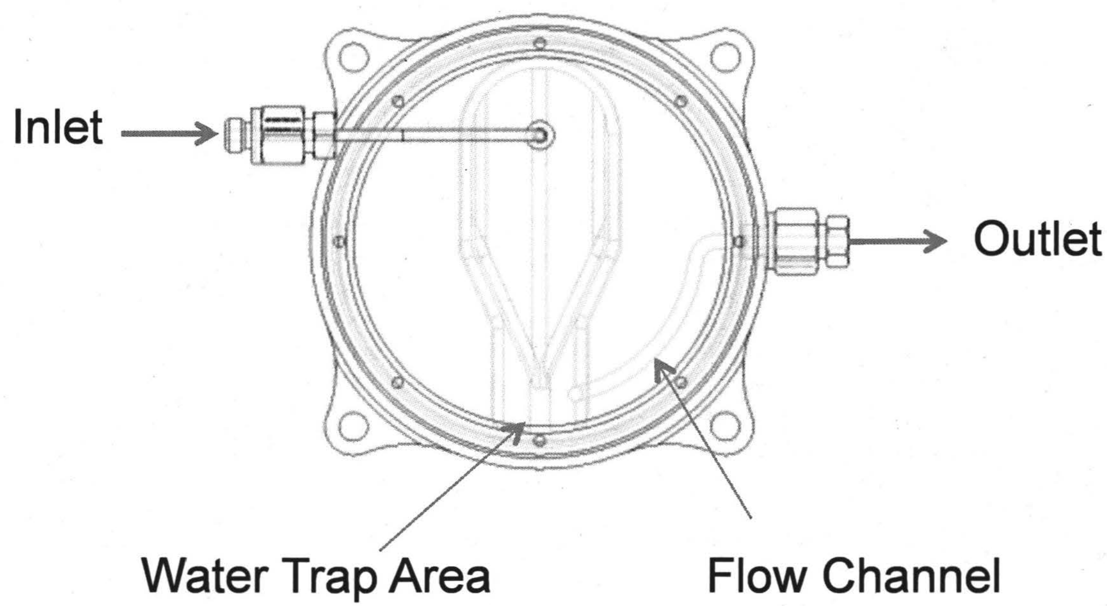
- Innovative idea
- Numerous design iterations
- Extensive testing
- Requirement to capture droplet of water on tip has evolved



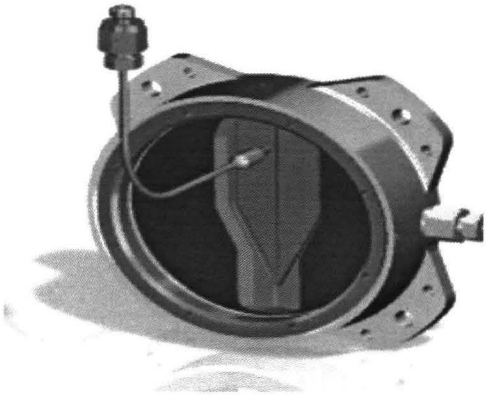


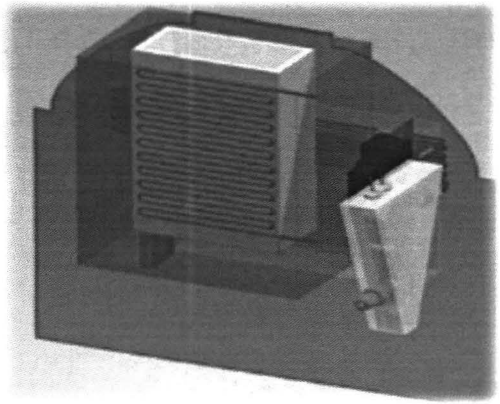
Theory of Operation

- Inlet gas flows from LAVA manifold at ~150C into WDD inlet tube
- Gas impinges condenser and disperses on the chilled surface (~-10C)
- Water vapor condenses on the surface creating droplets
- If enough water is present, droplets migrate towards condenser tip and forms hanging droplet
- Excess water accumulates in the water trap area of WDD
- To evacuate the system, inlet flow is shut off, WDD is heated, and the system is pulled to vacuum boiling of remaining water

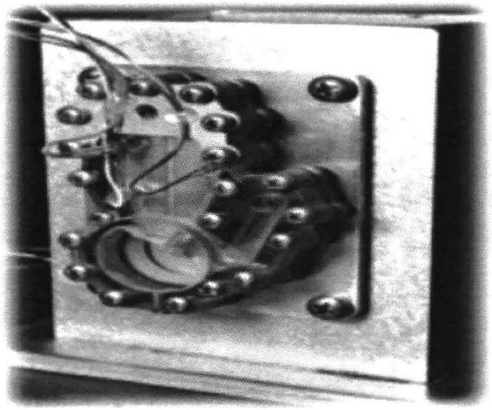


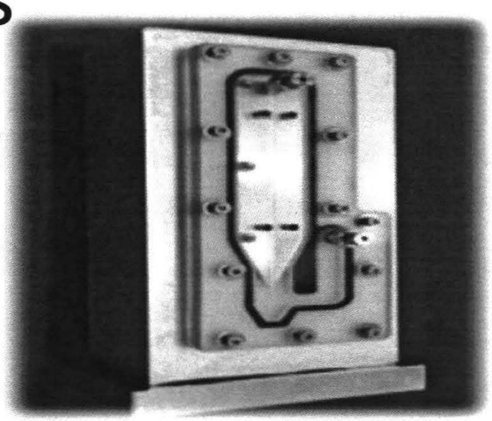
Design Changes Overview





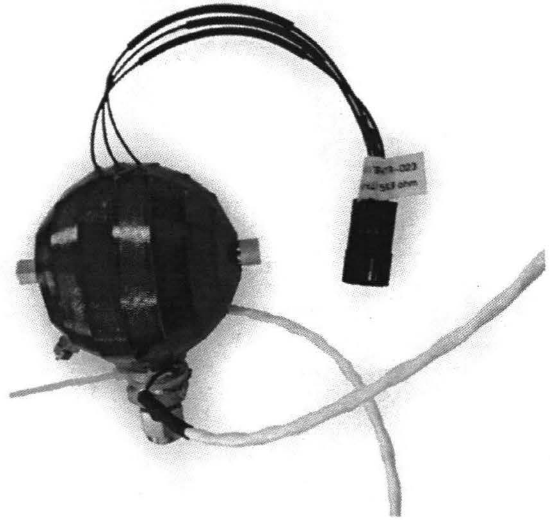
- Size
- Shape
- Coatings
- Textures
- Materials
- Housings
- Testing

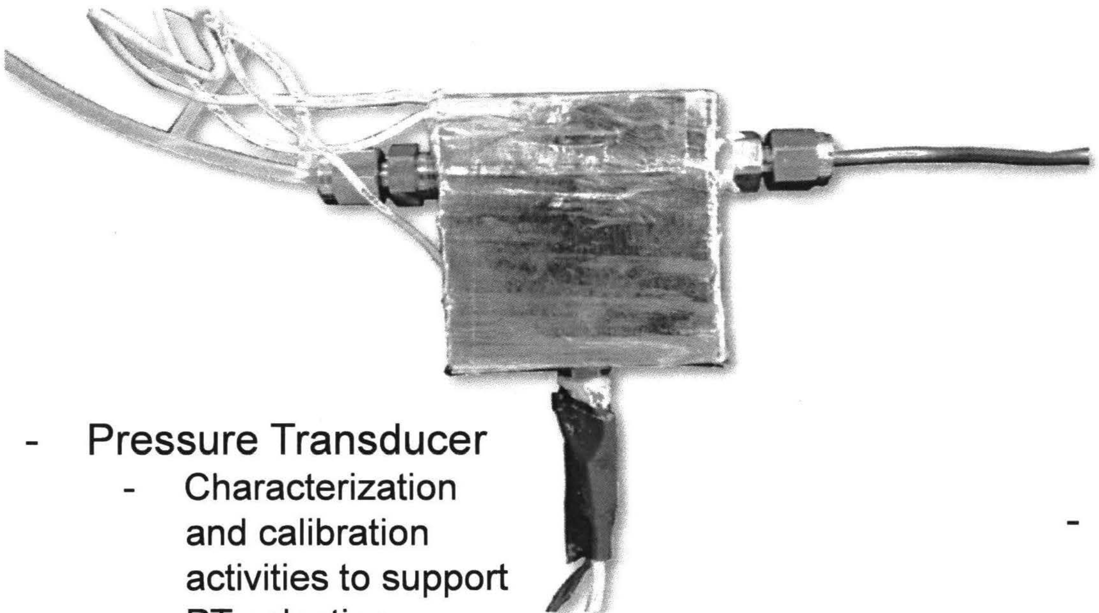




FSS EEE Component Testing and Evaluation

- Surge Tank Heater Testing
  - Risk Reduction activities to support heater control system development

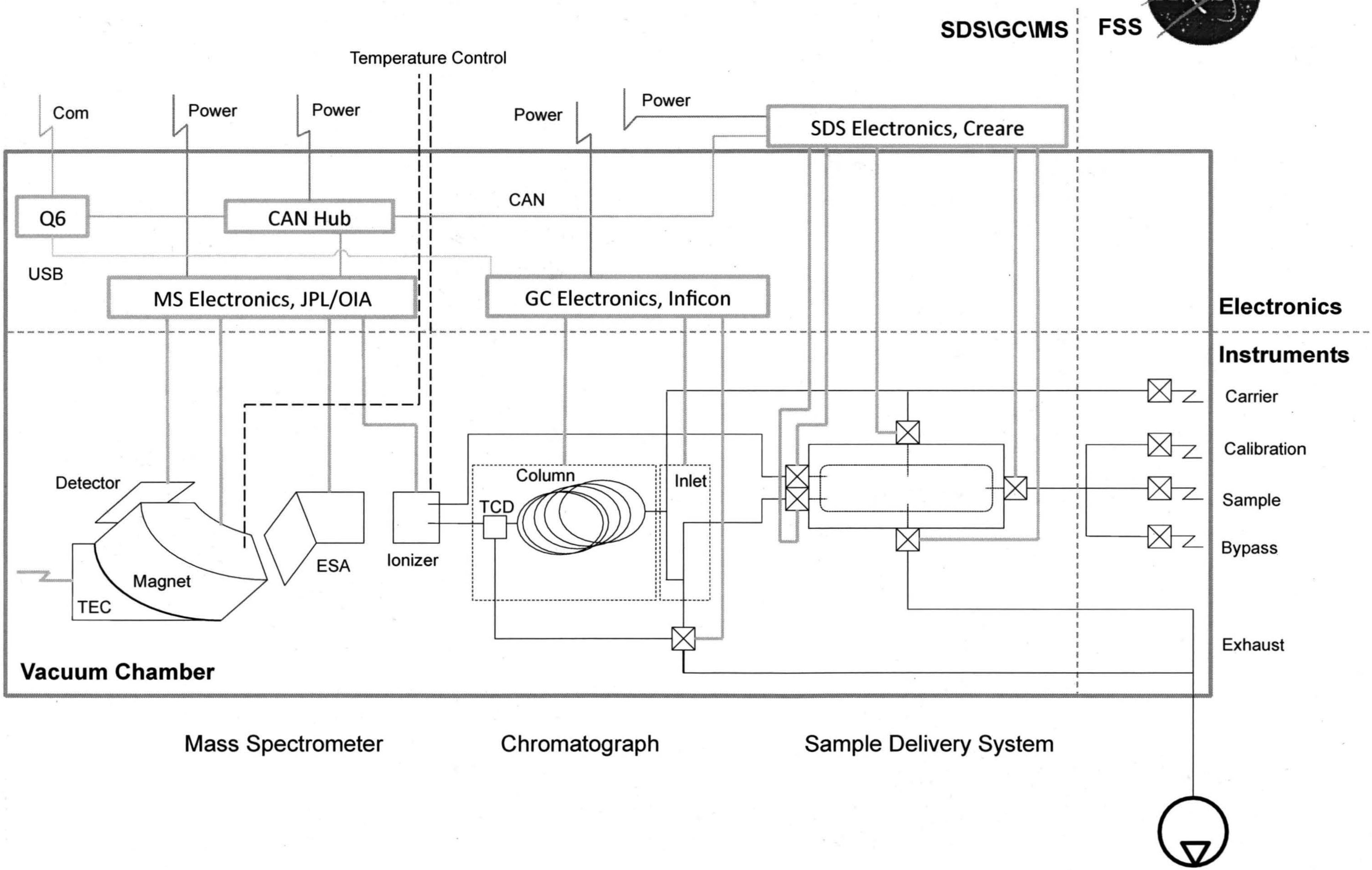




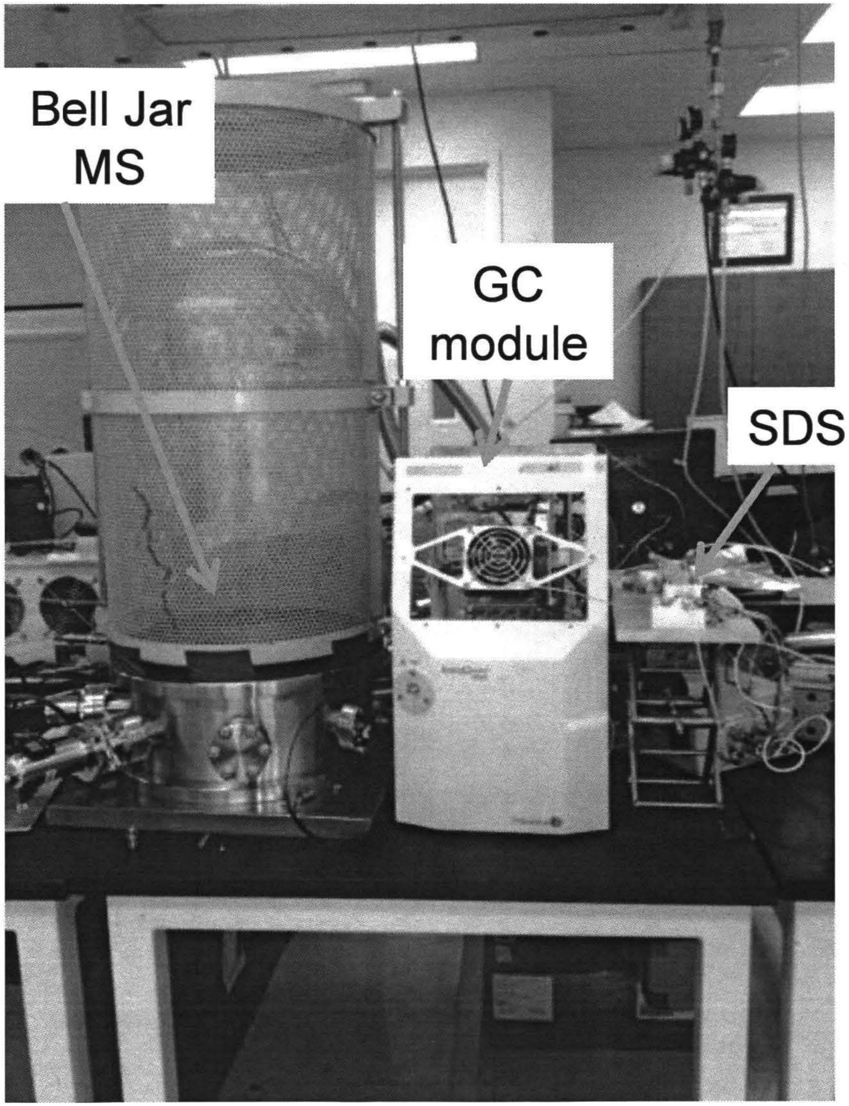
- Pressure Transducer
  - Characterization and calibration activities to support PT selection

- Mindrum Valve Characterization
  - Characterization testing to support control circuit development

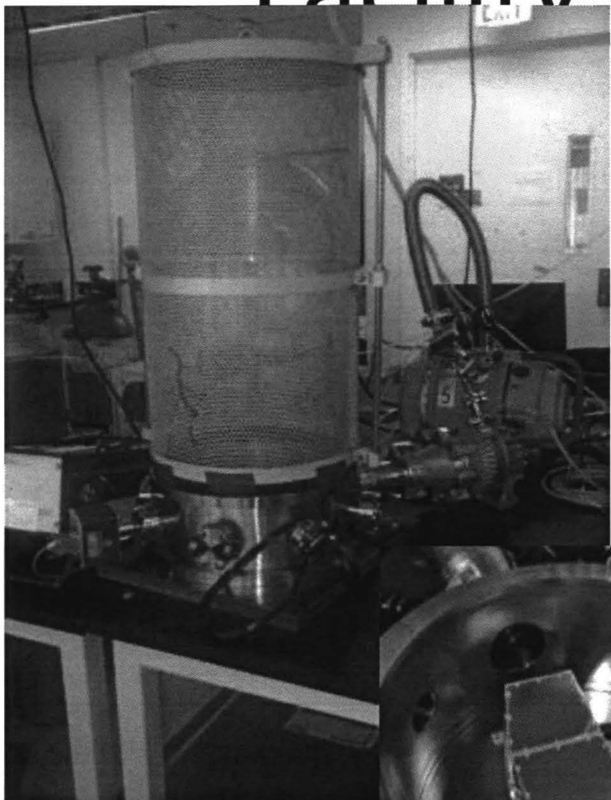
SDS/GC/MS Block Diagram

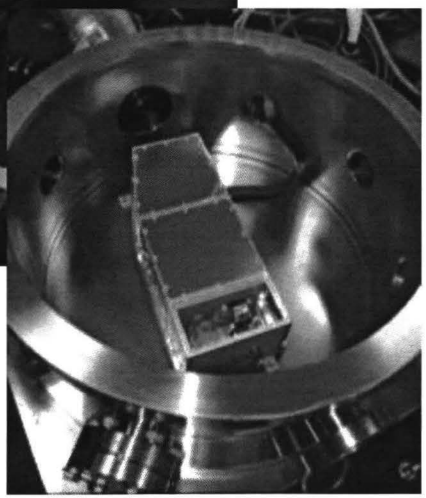


Hardware Status – SDS/GC/Bell Jar MS Integration at KSC

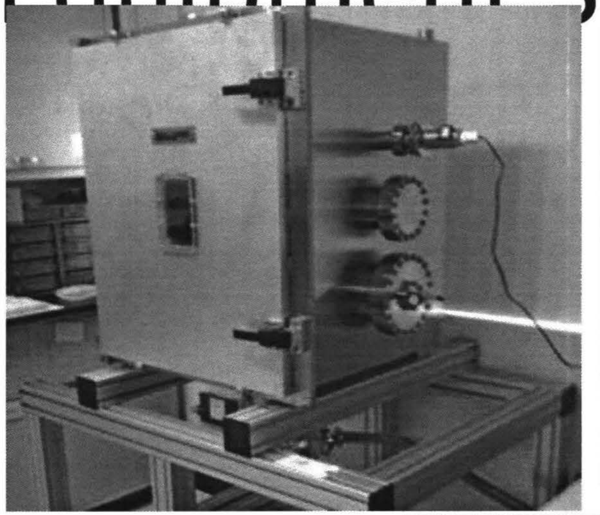


Facility and Equipment Status

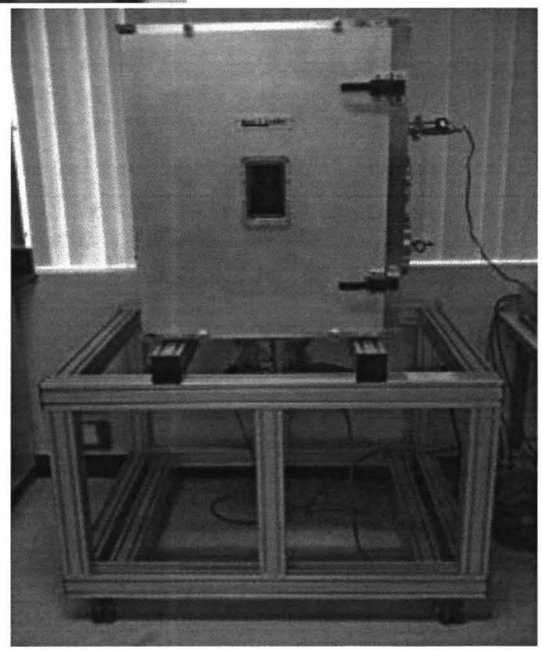




Bell Jar
O&C 1292
10^{-6} torr



Vacuum Chamber
O&C 1292



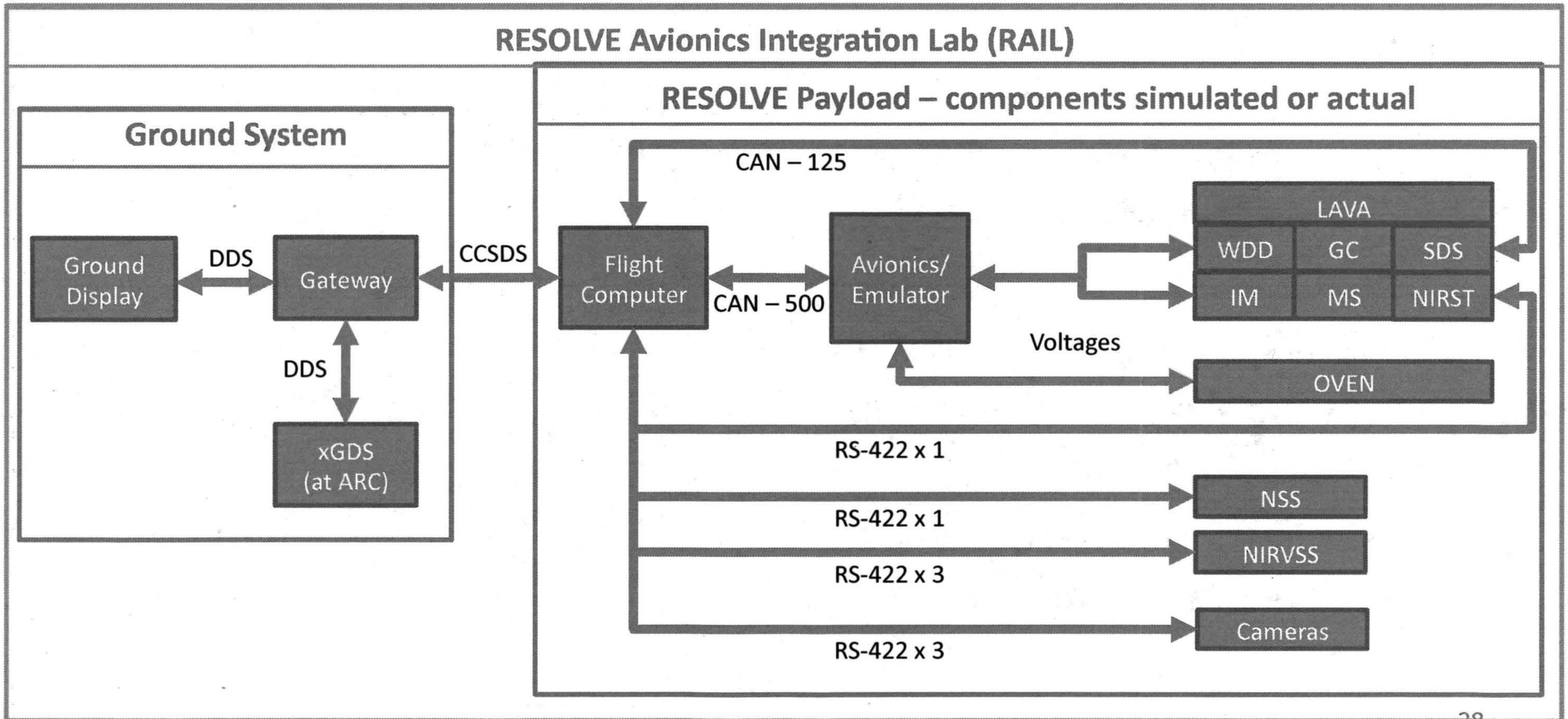
Chamber base pressure 10^{-9} torr

Software Subsystem

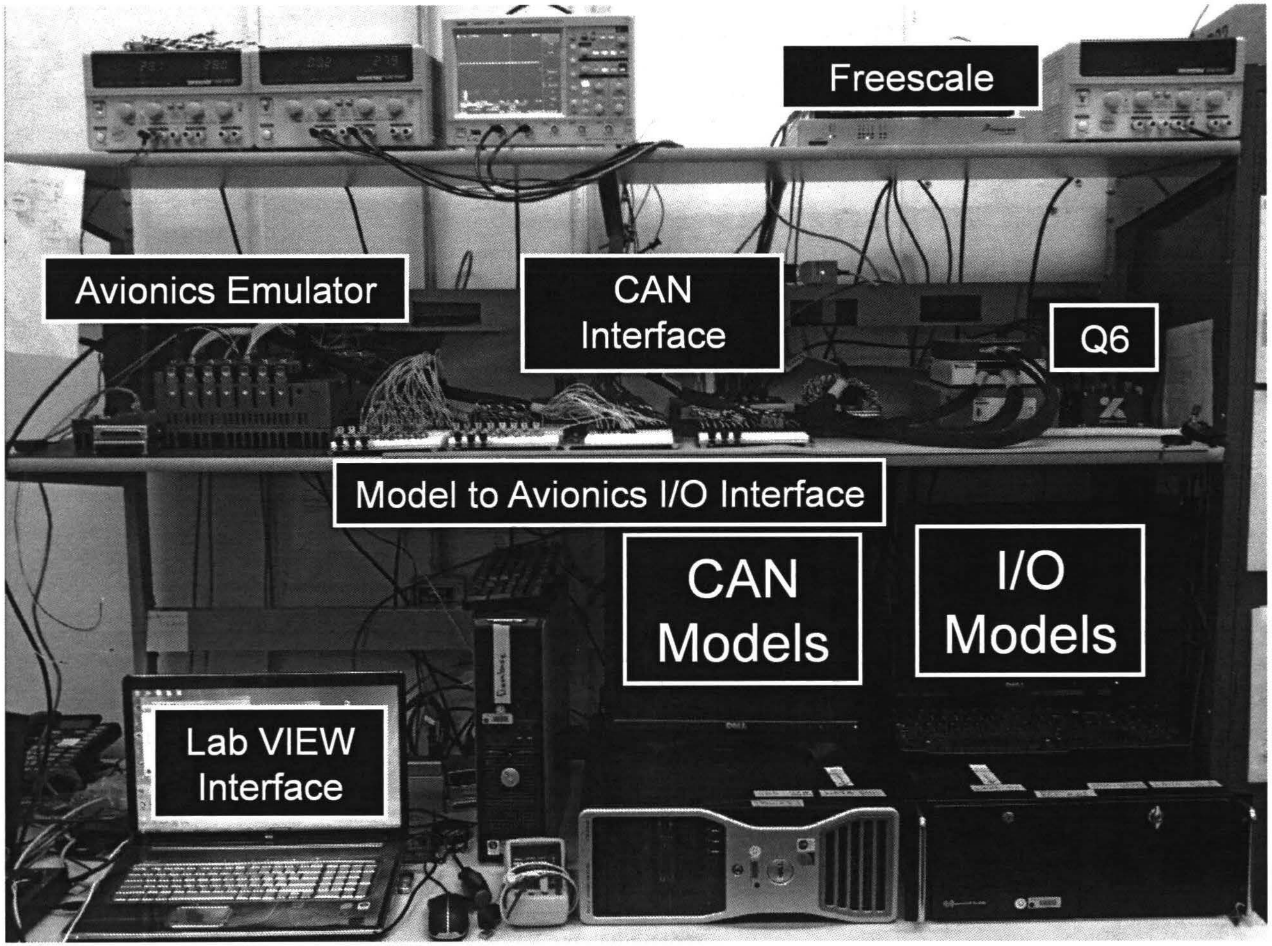
- During the Risk Reduction development phase, the RESOLVE Software Team will:
  - Create embedded flight software and ground system software using plans, processes & procedures required by NPR-7150.2A for Class C software development
  - Develop a test bed capable of emulating RESOLVE payload behavior called RESOLVE Avionics Integration Lab (RAIL) (reference slide x)
  - Create software for OVEN & LAVA subsystem development supporting test & demonstration activities
  - Establish communication interface approach with CSA for rover & drill systems
  - Demonstrate comprehensive set of Risk Reduction software systems (reference slide y)

RESOLVE Avionics Integration Lab (RAIL)

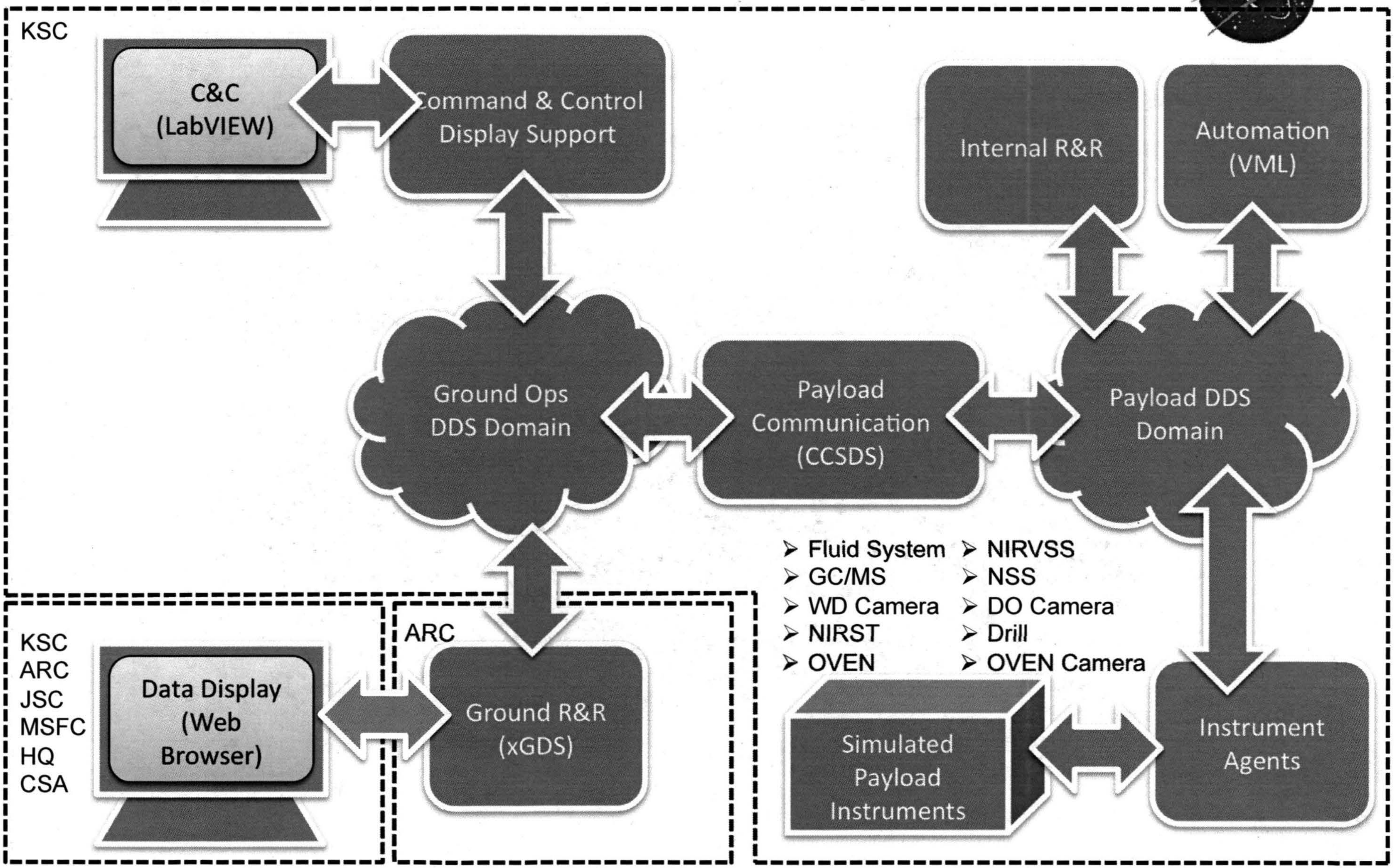
- Supports:
  - All levels of software testing
  - Avionics' and other subsystems' hardware testing
  - Validation of software requirements
  - Operator training including the simulation of failure conditions



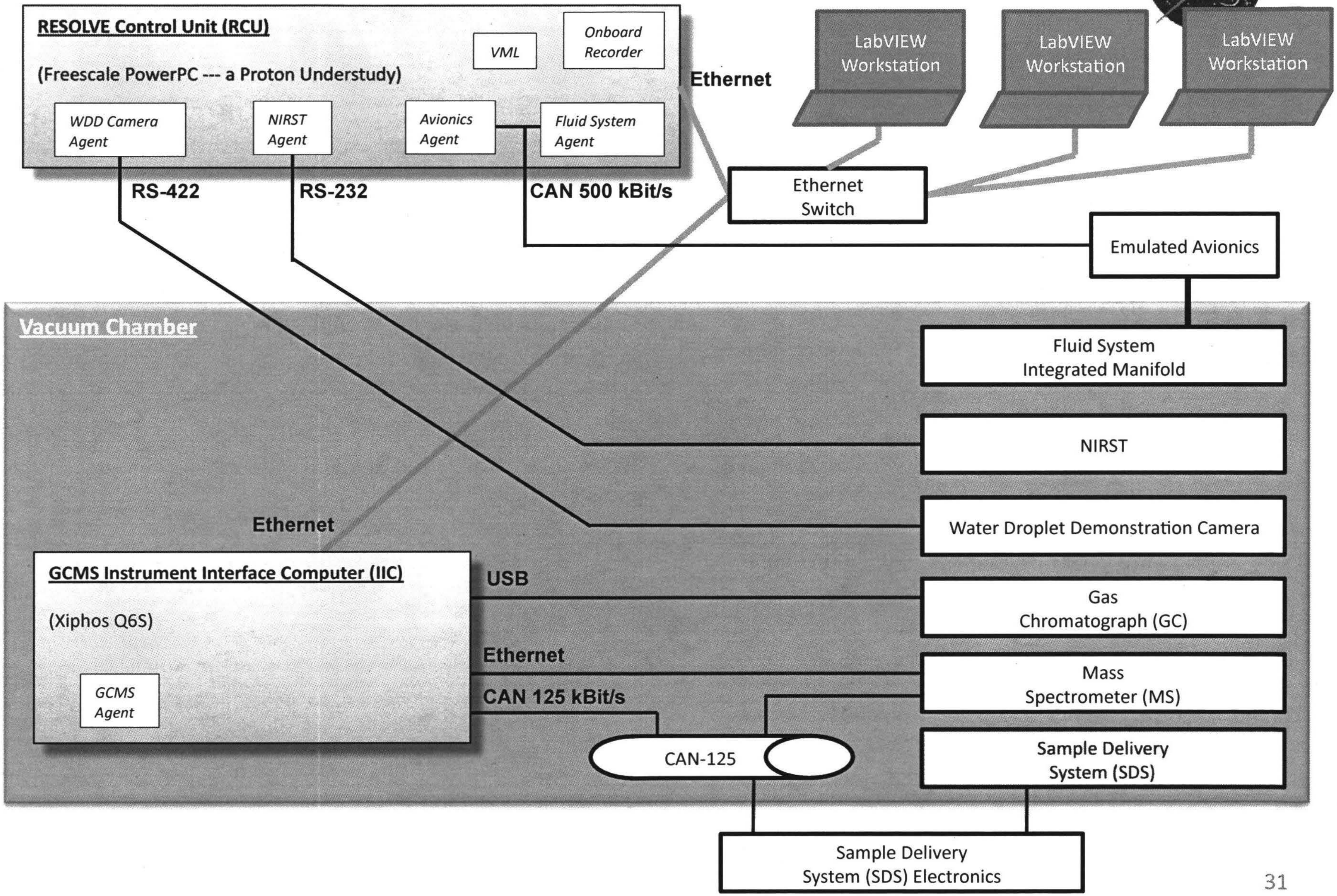
RAIL (RESOLVE Avionics Integration Lab)



Comprehensive RESOLVE Risk Reduction Software Demonstration

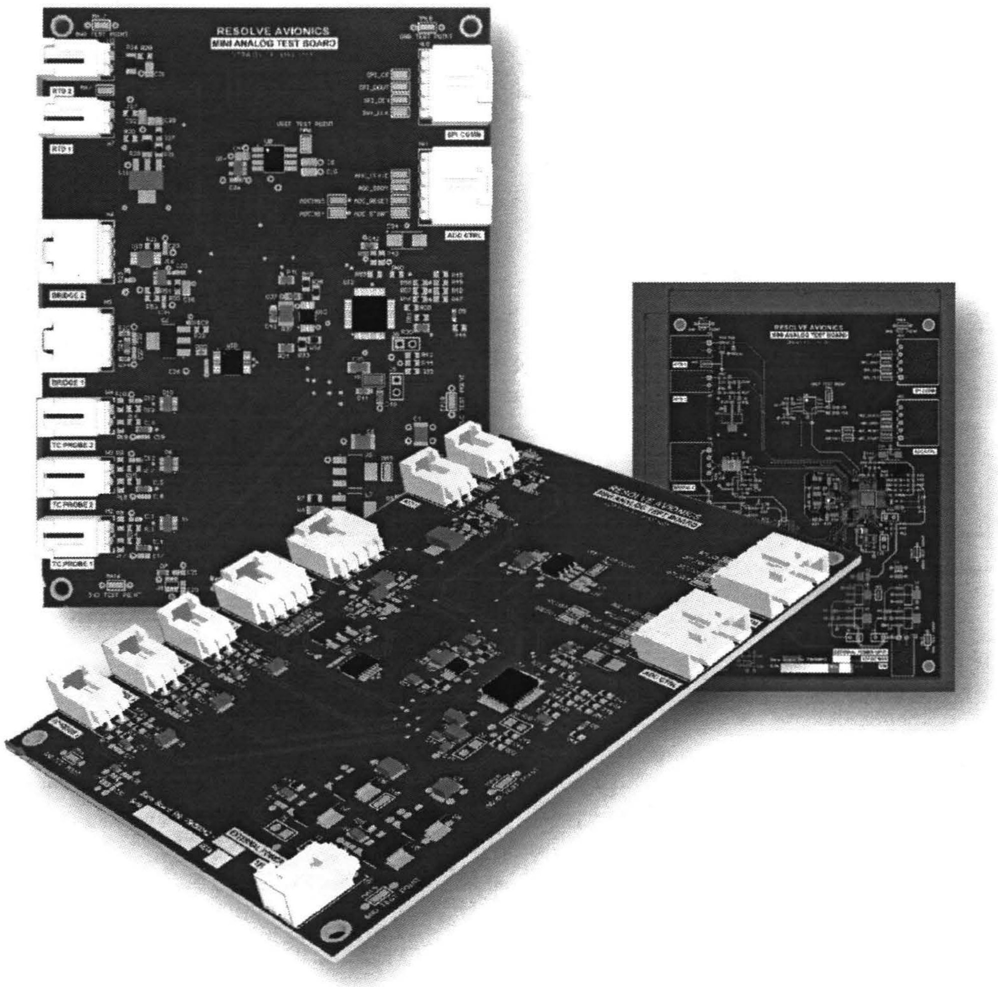


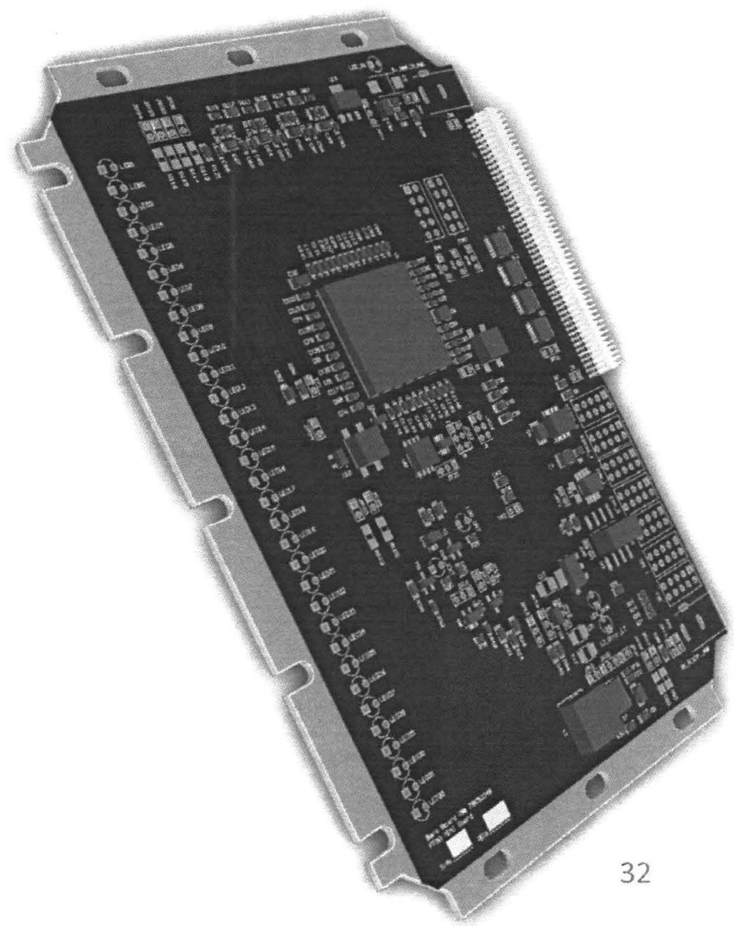
Instrument Development Software – LAVA Lab Architecture



Avionics: Custom Board Design and Layout

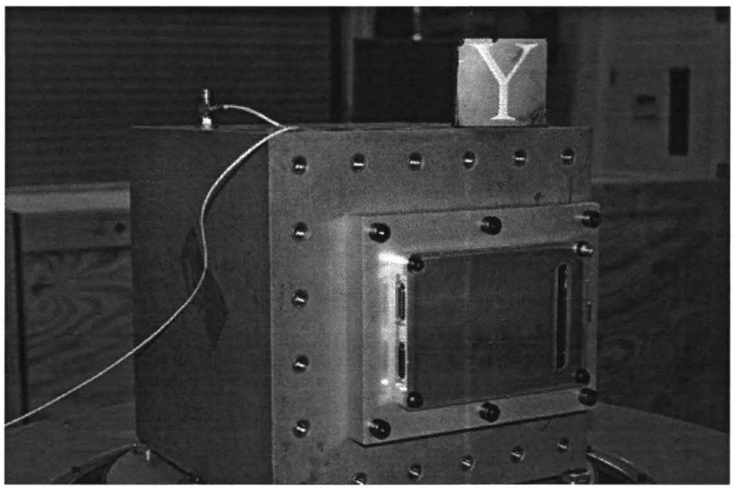
- We design and fabricate custom cards for lab tests as well as field deployment containing microcontrollers, Field Programmable Gate Arrays, and signal conditioning circuits.



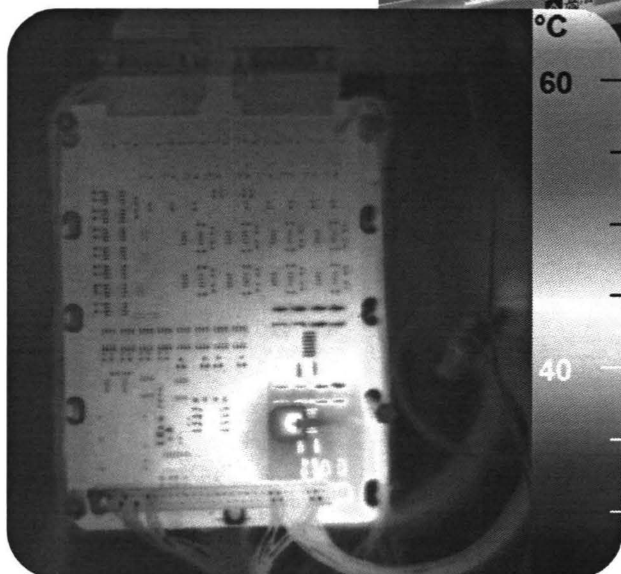


Board Environmental Testing

- We perform thermal cycling and ambient vacuum environmental testing.
- We also have access to vibration and electromagnetic testing laboratories and engineers.



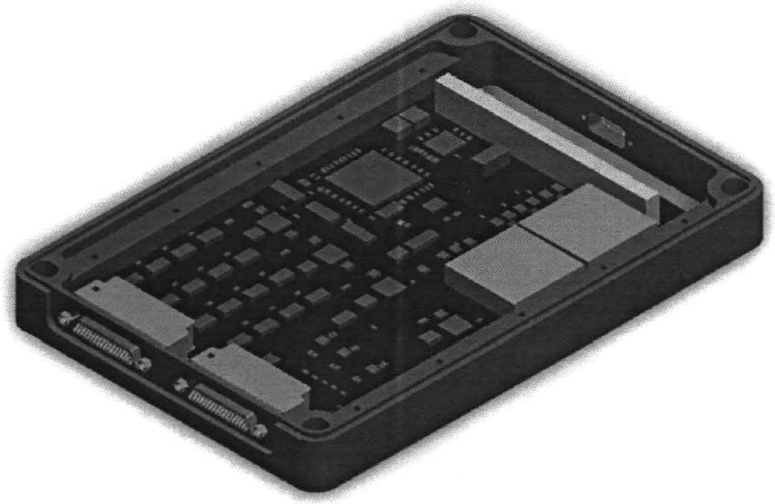
RESOLVE analog input card undergoing vibration testing



RESOLVE power switching card undergoing ambient vacuum testing

Enclosure and Slice Design

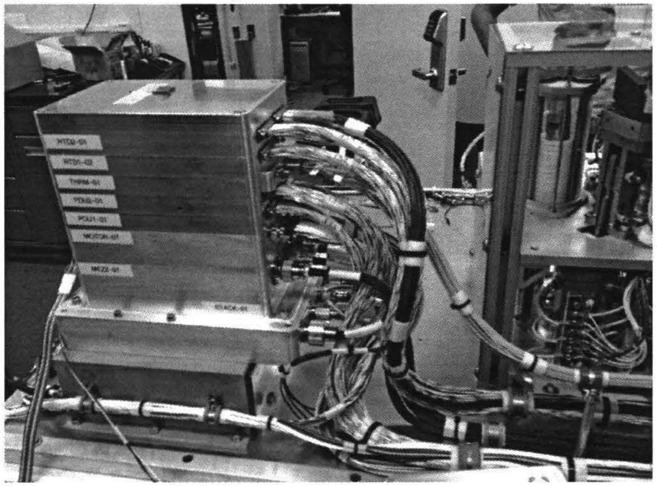
- Avionics assembly model for the Field Demo Unit tested in Hawaii



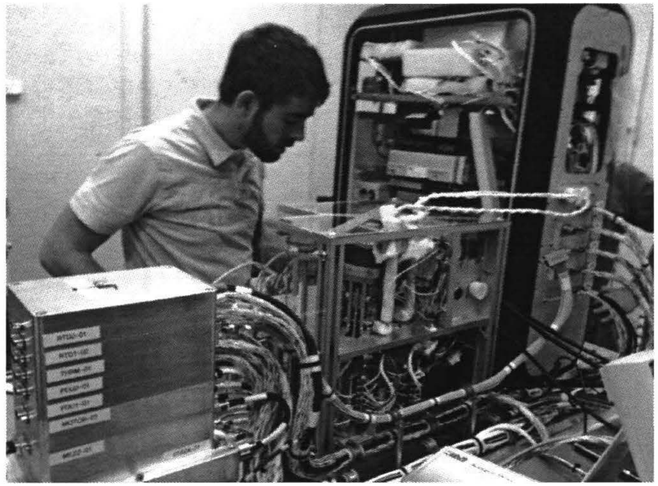
- Stack contains seven custom cards for sensor inputs, motor control, and power switching.

Avionics and Payload Integration for Field Demo

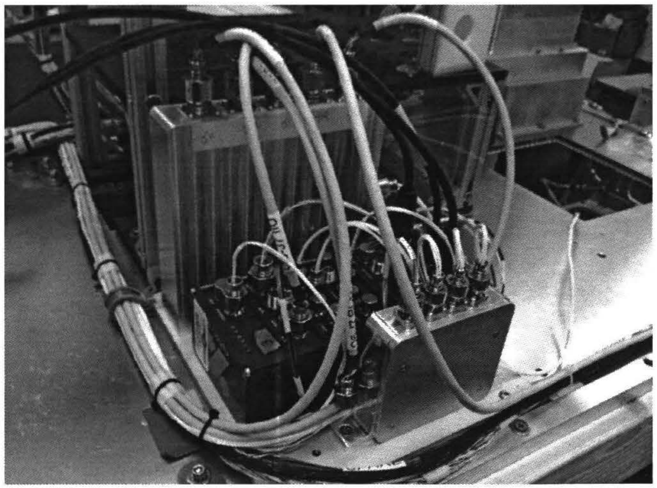
- **Integration snapshots**



Avionics Stack



Avionics Harness



Control Computers

Avionics Firmware Development

- During 2014, RESOLVE field demo software will be ported to the new, flight forward processors.
- Firmware (microcontroller code and VHDL) is being developed to put the closed loop control algorithms into the actuator cards.
- Model based design tools (Matlab, simulink) are being used to test firmware code and to simulate new algorithms.
- Our measurements database is operational and will be used to track user requirements and auto-generate code for linking system software to the avionics firm

MMLdb

- Measurements Database

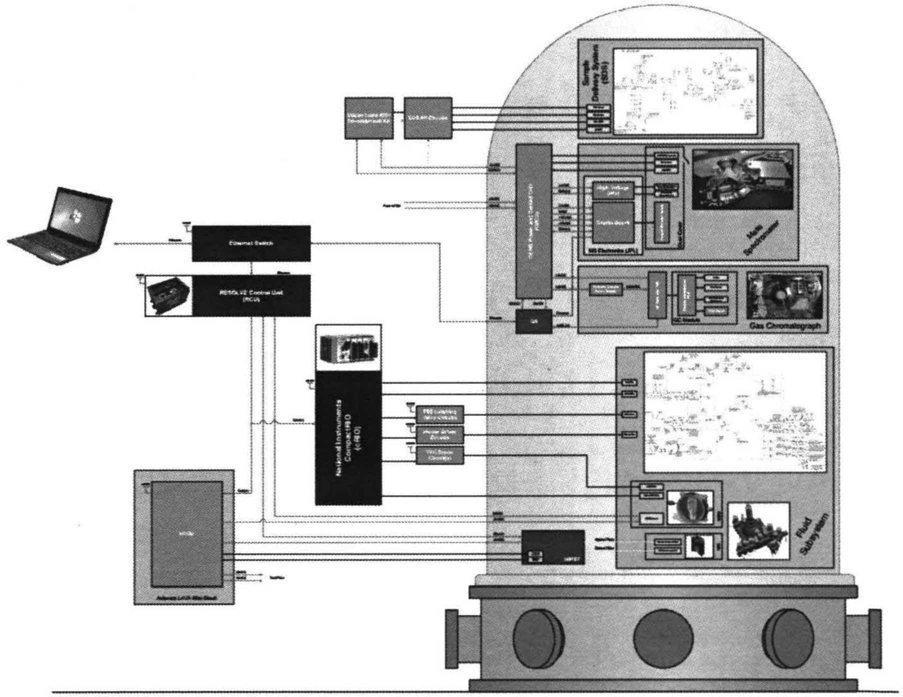
Avionics | Software | Import | Admin

RESOLVE Hardware Designators

Designator ID	Subsystem	Description	Class	Effectivity
BRK-103	OVEN	Arm Vertical Motor Brake	Actuator	ETU Only
BRK-105	OVEN	Segment Removal Station Gripper Motor Brake	Actuator	ETU Only
BRK-106	OVEN	Segment Removal Station Brush Motor Brake	Actuator	ETU Only
BRK-108	OVEN	Crucible Lift Assembly Motor Brake	Actuator	ETU Only
CAM-001	LAVA	WDD Camera	Actuator	ETU Only
HTR-001	LAVA	OVEN Hydrogen Inlet Line Heater (1 of 2)	Actuator	ETU Only
HTR-002	LAVA	OVEN Volatile Output Line Heater (1 of 2)	Actuator	ETU Only
HTR-003	LAVA	GC/MS Inlet Line Heater (1 of 2)	Actuator	ETU Only

Supporting Complex Integrated Testing of the RESOLVE Fluid Systems

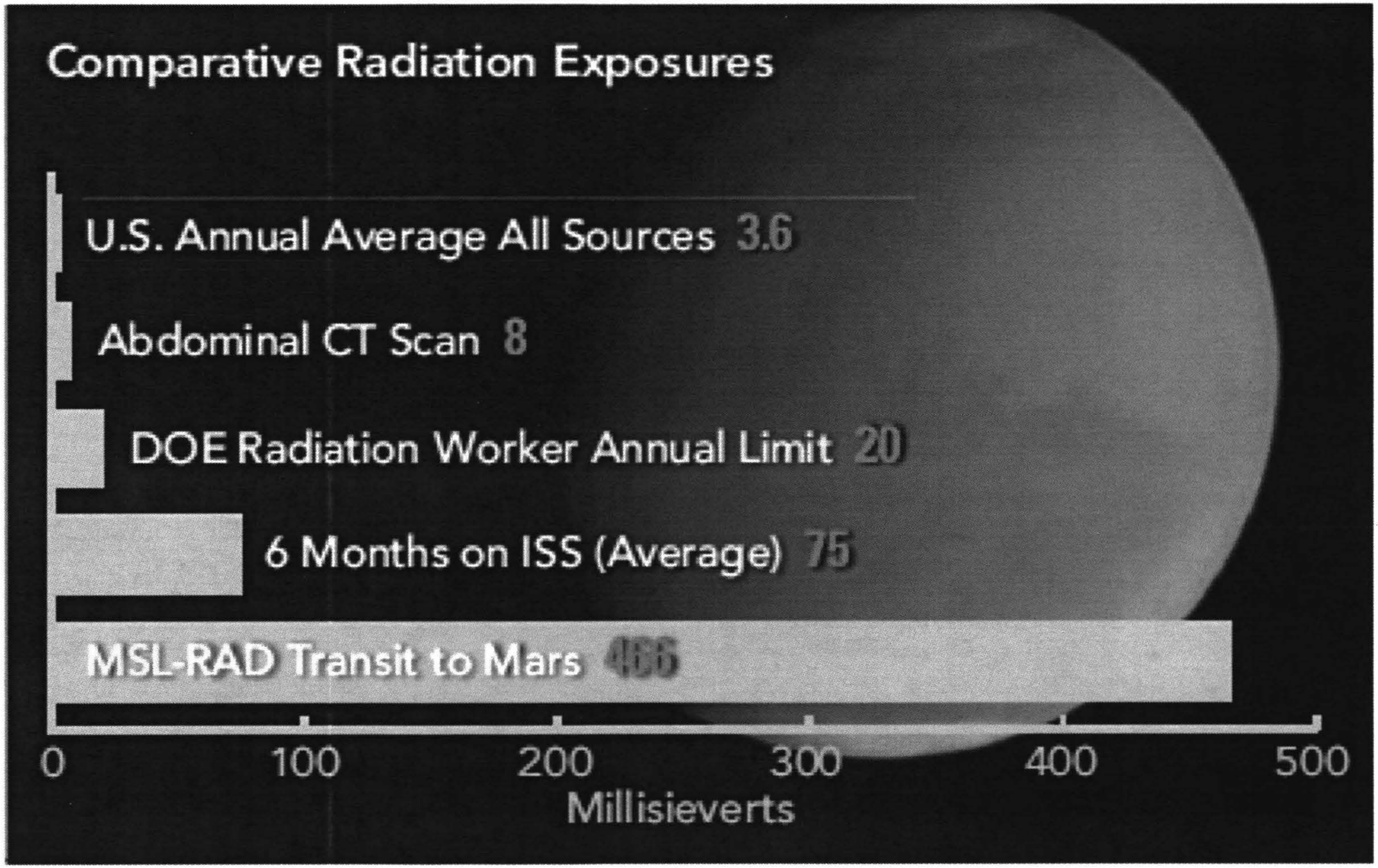
- Wiring/Cable Plant Diagrams
  - Cable Plant Concept Drawings (OASIS link)
  - GP-435 Compliant ETU Block Diagrams and Cable Interconnect Diagrams in work by ESC personnel (Drew Schmidt)
- Component Selection
  - Low Outgassing Wiring (MIL-W-22759/33)
  - Low Outgassing Heat Shrink (PVF)
  - Low Outgassing Heat Shrink Labeling and Marking
- Custom Design Efforts
  - Vacuum Chamber Flange
  - cRIO Interface Boards
  - Breakout Boards
  - cRIO LabView Code



Exploration: Radiation Shielding

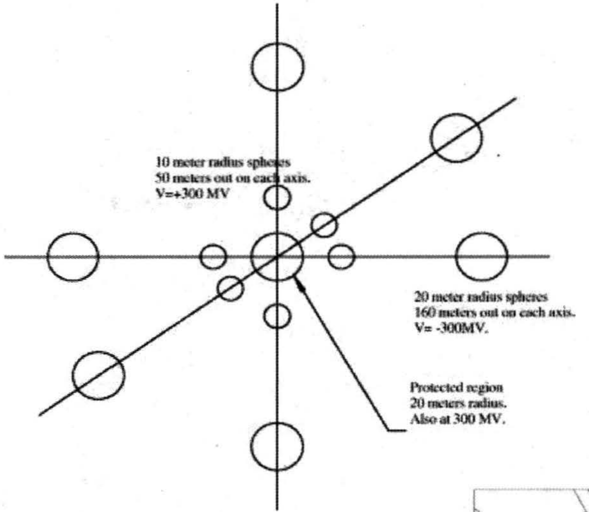
- Radiation exposure to crews on long duration missions is considered to be one of the top technology risks for Mars exploration.
- Two components: solar wind protons and heavy galactic nuclei (Galactic Cosmic Radiation (GCR)).
- GCR have MeV/nucleon energies and are very difficult to stop plus interaction with shielding and tissue generates secondary's so dose actually increases with shield depth for all substances with neutrons (not hydrogen).

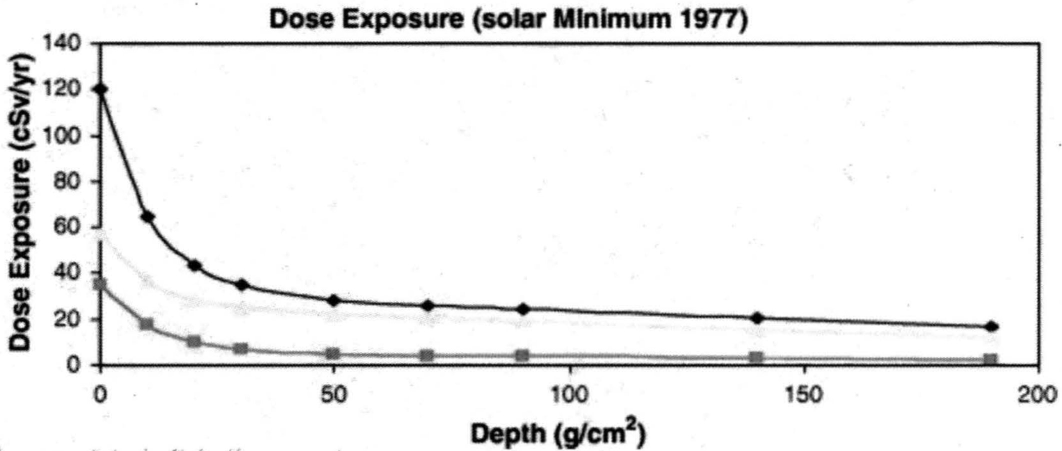
Recent MSL Radiation Measurements

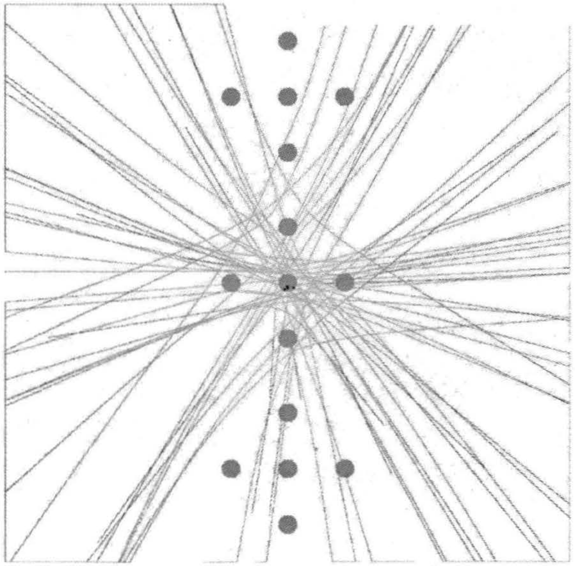


Ref: “Radiation Will Make Astronauts’ Trip to Mars Even Riskier,” R. Kerr, Science, 31 May 2013

Electrostatic Space Radiation Shielding



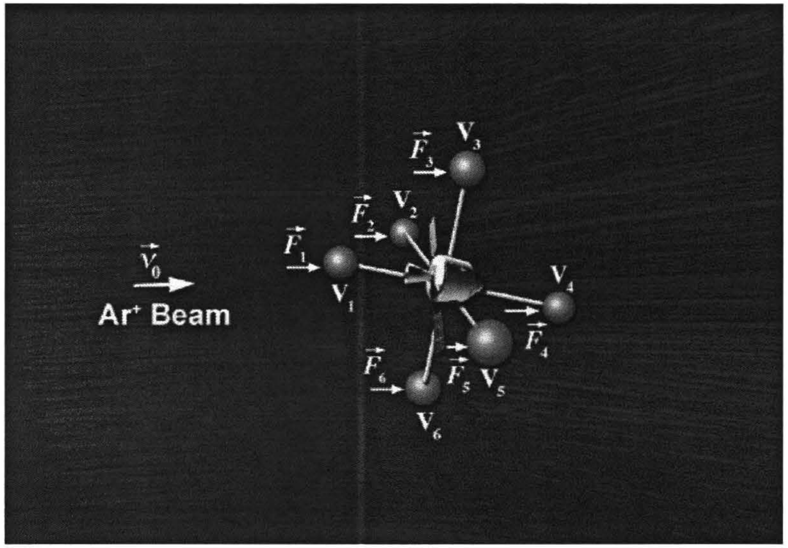


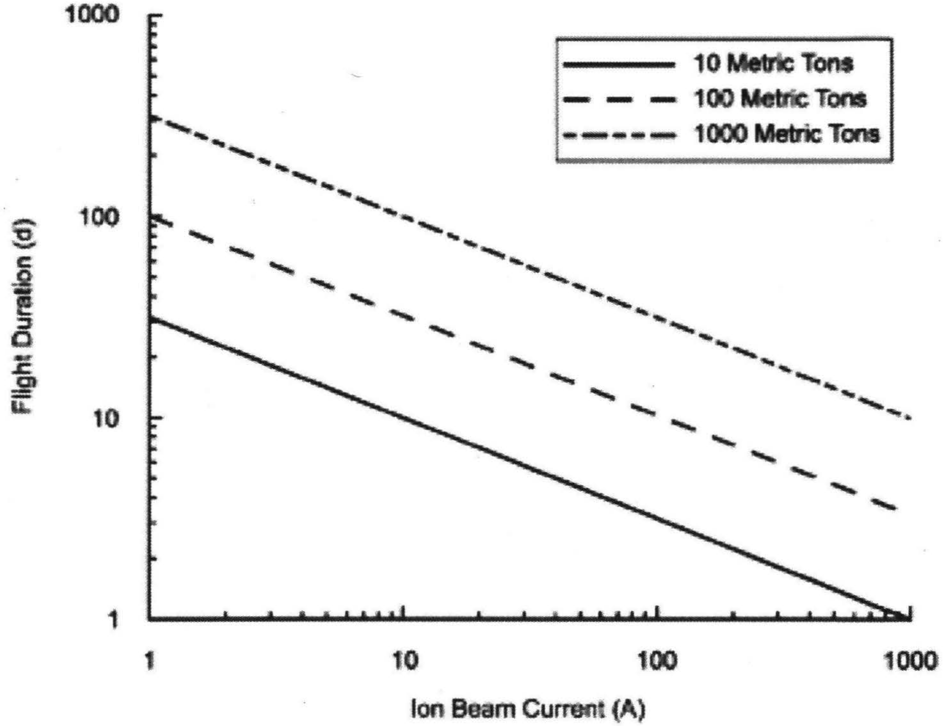


The blue (top) curve refers to the exposures from the unprotected (unmodified spectrum). The yellow (middle) curve refers to the exposure behind a polyethylene shielding and the pink curve (lowest) curve refers to the exposure with the modified spectrum with electrostatic shielding.

Ref: "Electrostatic Space Radiation Shielding," Tripathi, Wilson, Youngquist, Advances in Space Research, 15 Sept. 2008

The ES Shield for Propulsion

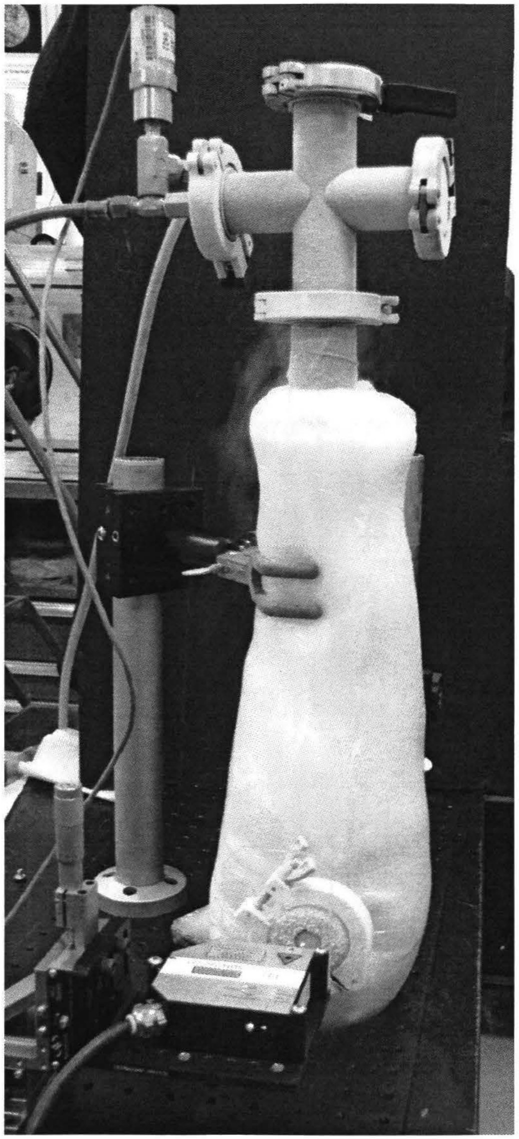




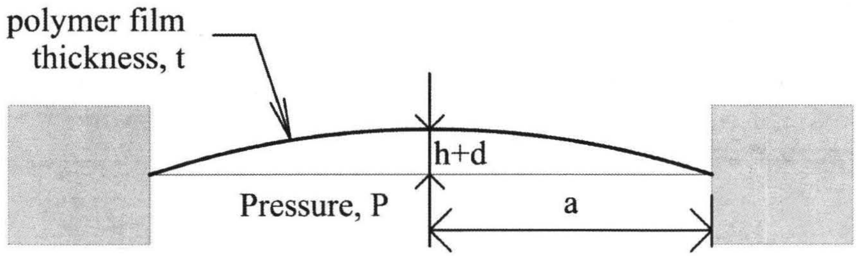
Flight duration (*d*)(d) as a function of ion beam current (*A*)(A), with spacecraft mass (metric tons) as a parameter, for a journey equal to the Earth–Moon distance (1-MeV Ar^+Ar+ ions).

Ref: "A lunar-based spacecraft propulsion concept—The ion beam sail," Brown, Lane, Youngquist, Acta Astronautica, May-June 2007

Liquid Hydrogen Shielding



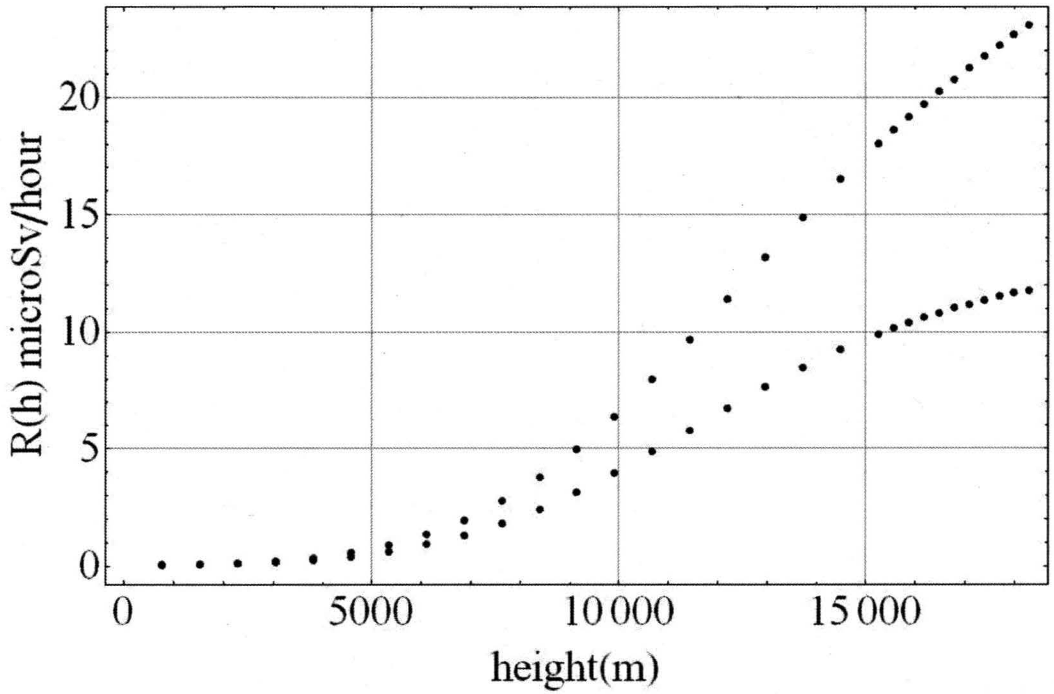
- Hydrogen contains few neutrons so the possibility of a liquid hydrogen radiation would provide low weight and favorable shielding.
- A team including the Cryo Lab, APL and Polymer Lab, led by Martha Williams, produced: "Measurement of the Mechanical Properties of Thin Film Polymers at Cryogenic Temperatures"



$$P = \frac{8Et}{3a^4(1-\nu)}(h+d)^3 + \frac{4\sigma t}{a^2}(h+d)$$

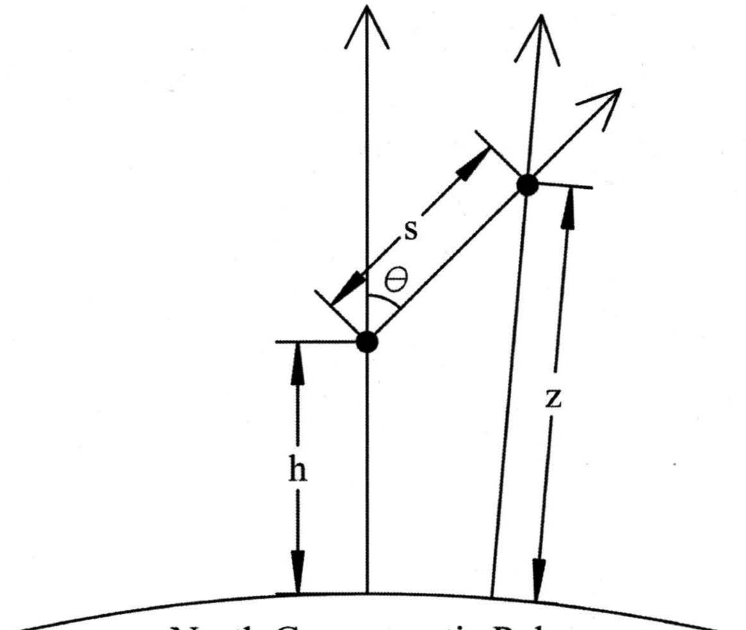
Authors: W.L. Johnson, R.C. Youngquist, T.L. Gibson, S.T. Jolly and M.K. Williams

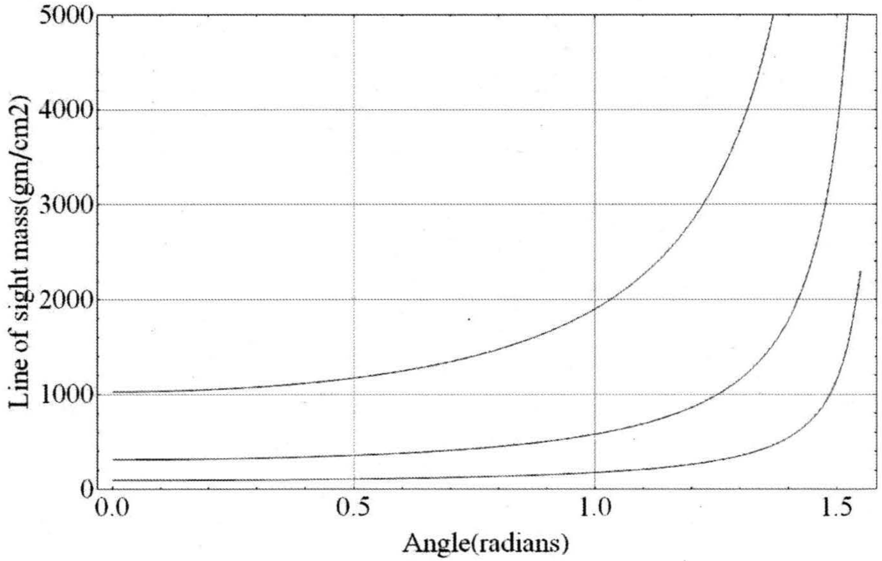
Thick GCR Shielding Using Atmospheric Data



FAA CARI-6 effective radiation doses from GCR versus height at the north geomagnetic pole for June 2000, a solar maximum when the radiation levels were low, and for June 2009, a solar minimum when the radiation levels were high.

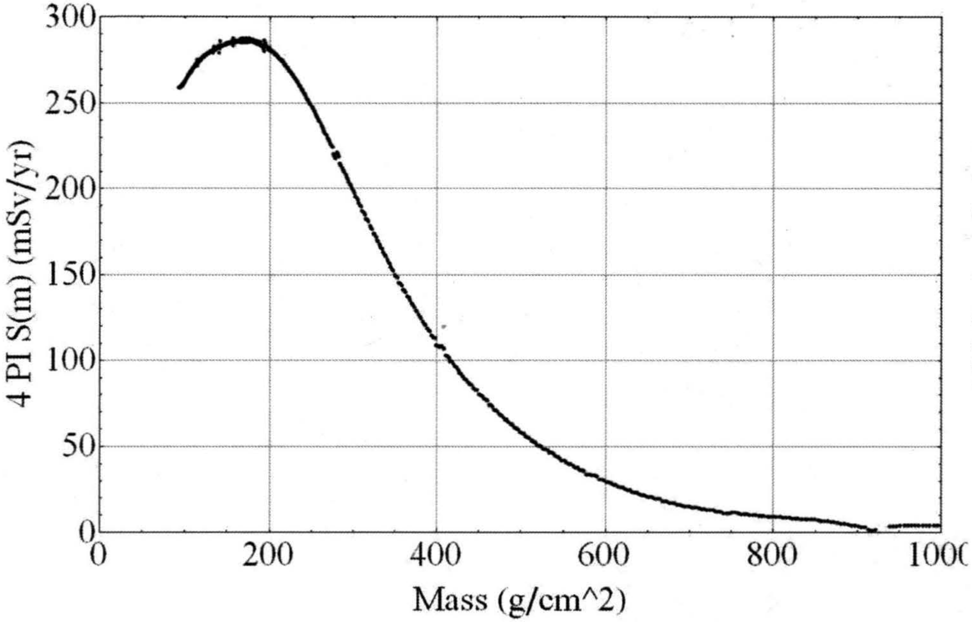
Thick GCR Shielding Using Atmospheric Data



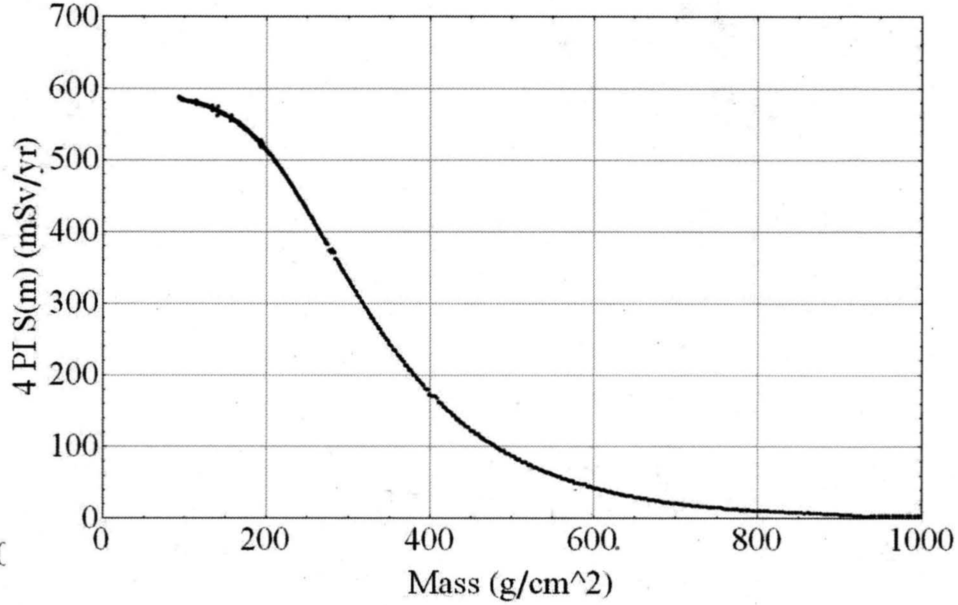


Plots of the total atmospheric mass between an observer and space versus the angle in radians measured down from vertical. The highest plot corresponds to ground level, the middle plot is at a height of 9000 m, and the lowest plot is at a height of 18000 m.

Thick GCR Shielding Using Atmospheric Data



Solar Maximum Dose



Solar Minimum Dose

The FAA data allowed us to create an inverse plot of the shielding of the atmosphere as a shield versus thickness through some fairly clever math modeling.

Surface Acoustic Wave Sensors

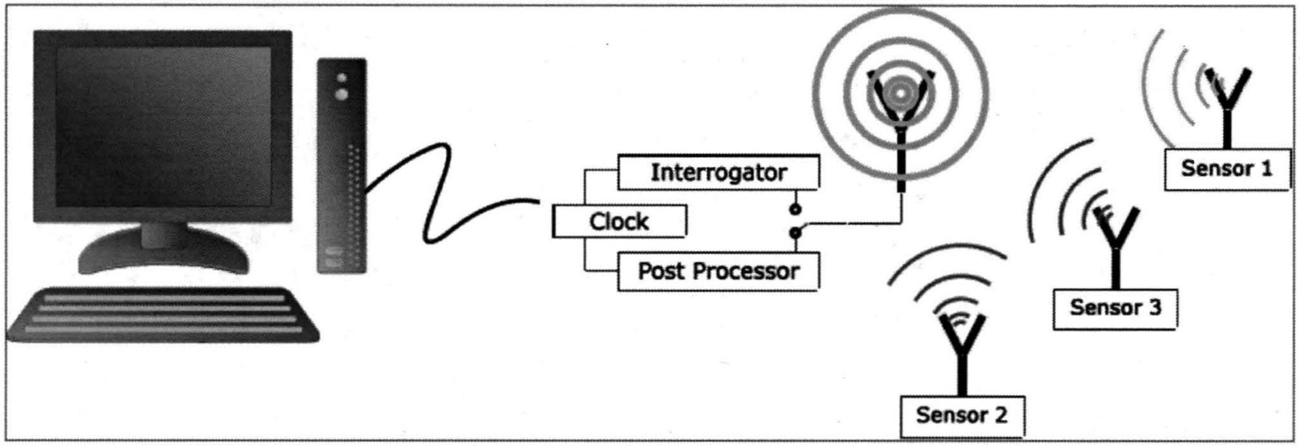
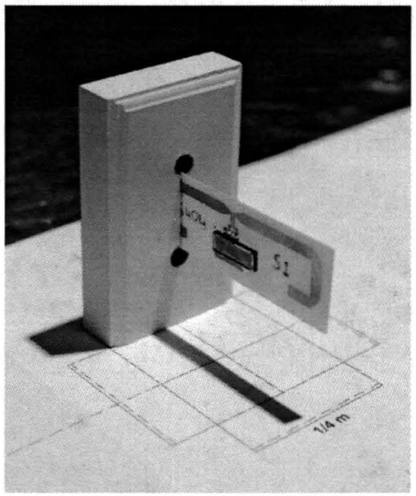
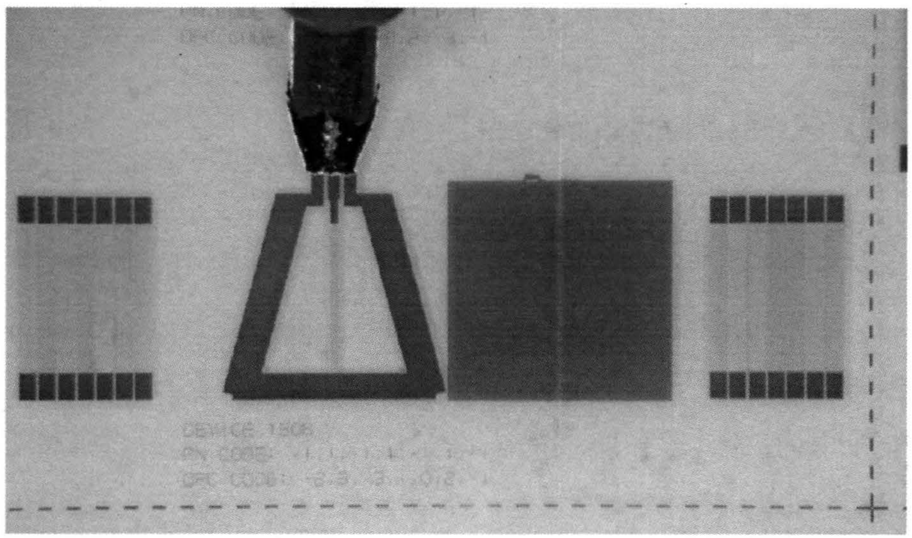


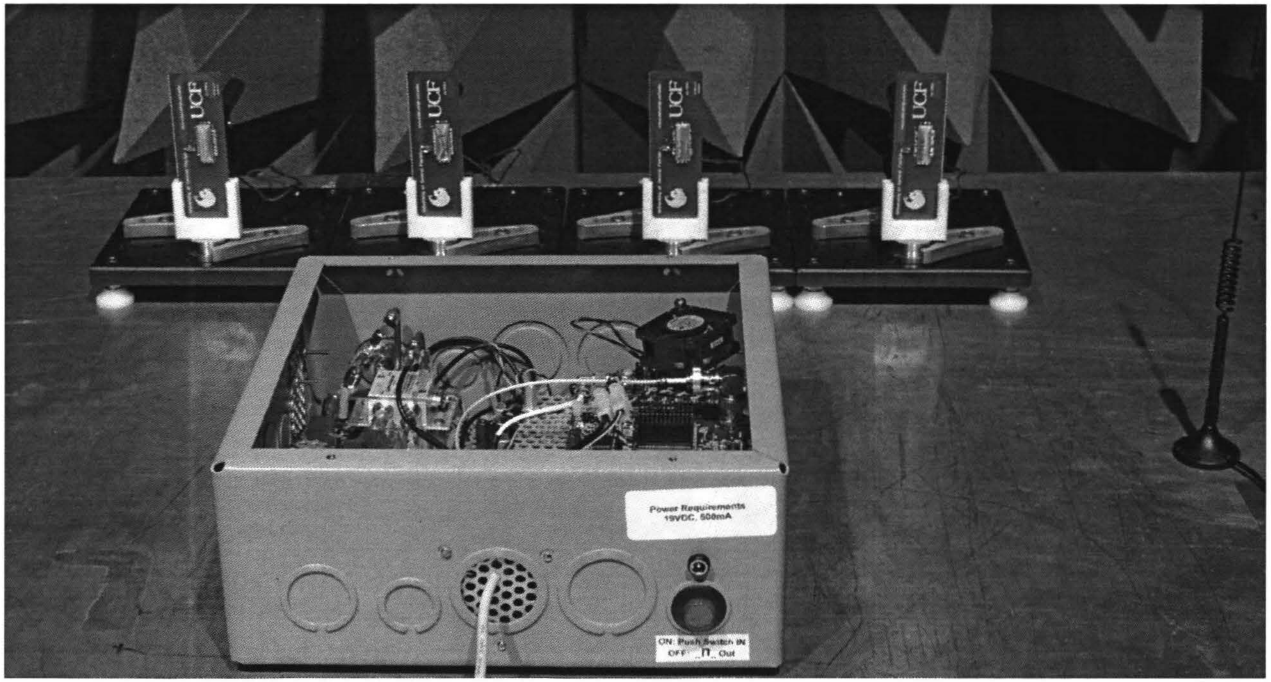
Fig.1 A multiplexed sensor system would have an interrogator that sends out RF pulses to echo based sensors. The return signals from these sensors are picked up by the interrogator and processed to determine which sensor is which and the value of the sensed parameter.





Surface Acoustic Wave Sensors

- In 2011, a UCF/Mnemonics Inc. was delivered under an STTR Phase 2



2012 Hydrogen SAW Sensors

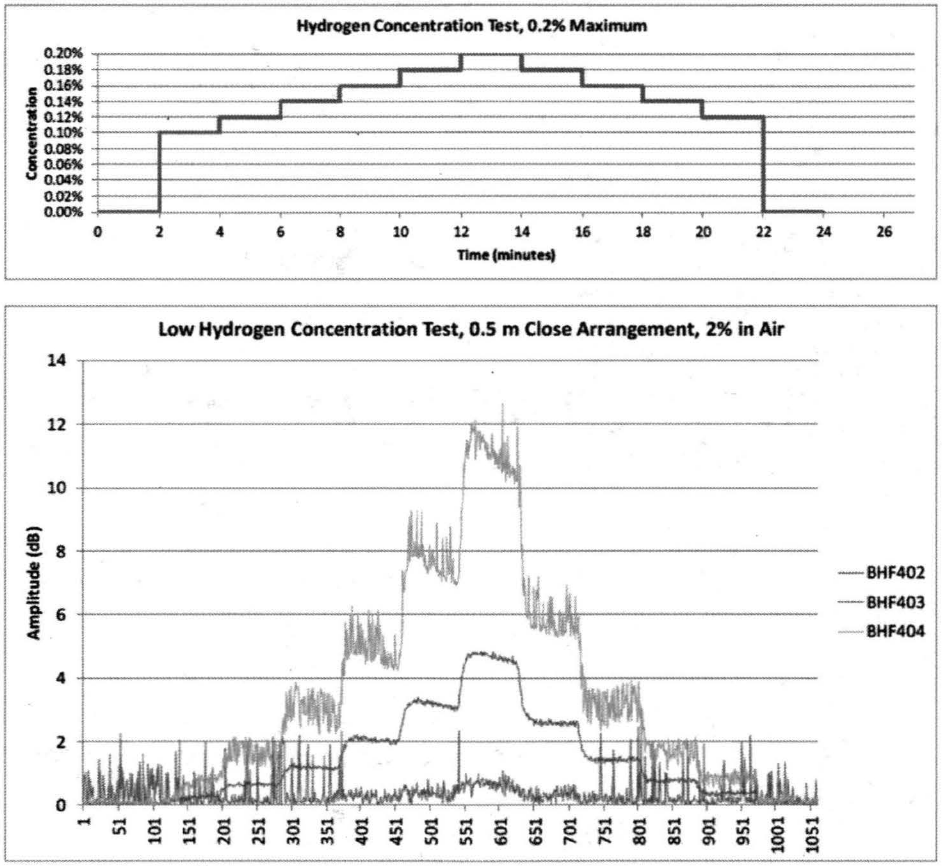
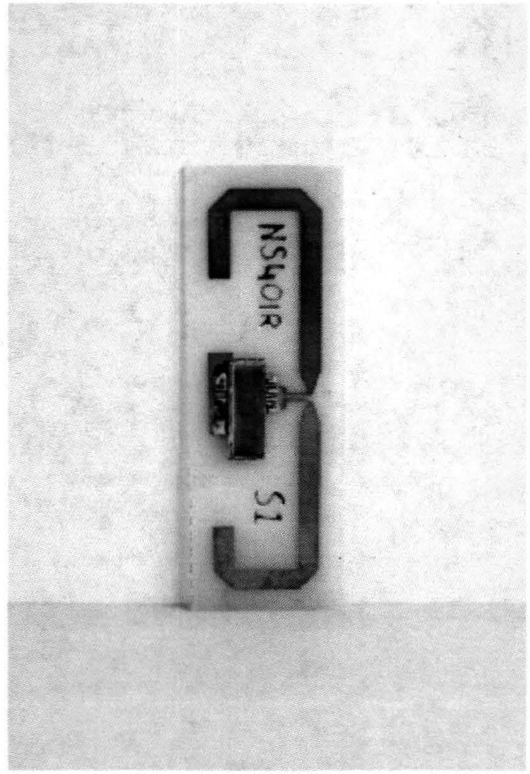


Figure 45. Low hydrogen concentration test, input profile and results



Supplied temperature sensor

Ref: NASA TDL-0634 Characterization test Report for the Mnemonics-UCF Wireless Surface Acoustic Wave Sensor System, Feb, 2013

SAW Sensors

- Current Work:
  - Modeling the performance of Hydrogen sensors
  - Multiplexing to an arbitrary number of sensors (NASA/UCF patent in work).
  - Plans to test SAW sensors in space on CubeSat platform.

Satellite Formation Flying: Propelling, Tracking, and Powering

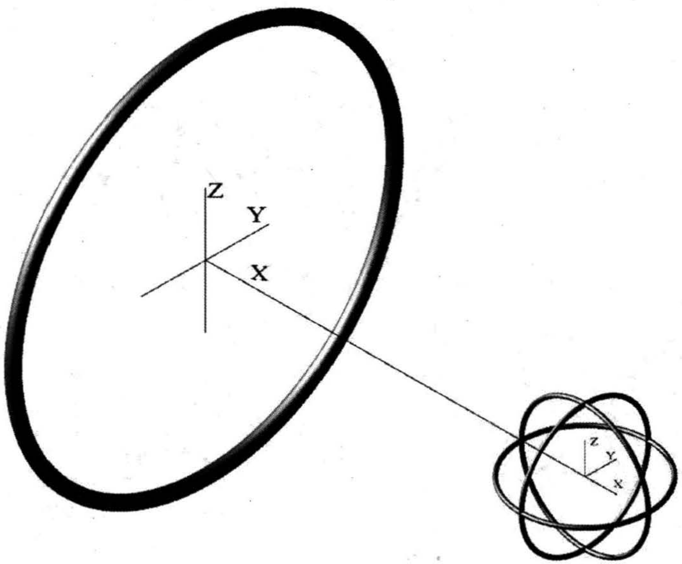
NASA Need:

NASA Roadmap TA 05, Communication and Navigation Systems, states that an Autonomous Precision Formation Flying concept with position and navigation is needed by 2022.

NASA needs to fly clusters of small satellites to create adjustable telescopes, interferometers, gravity wave detectors, and eventually have cognitive swarm operation of nanosats.

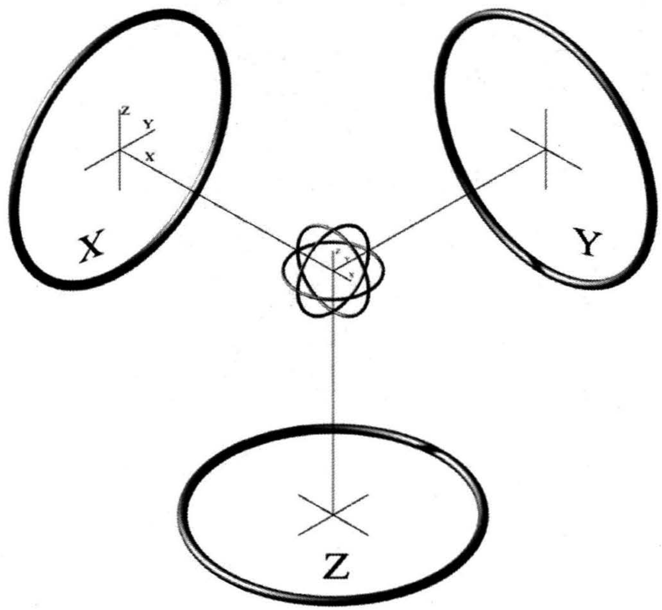
Ref: Alternating Magnetic Field Forces for Satellite Formation Flying, Acta Astronautica, Youngquist, Nurge, Starr, March 2013

Satellite Formation Flying: Propelling, Tracking, and Powering

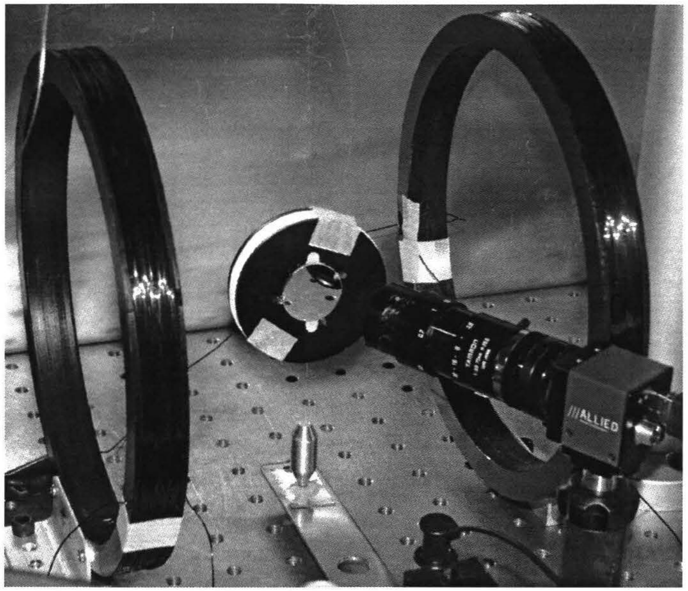


Oscillating current at a known frequency through a large loop will generate an oscillating magnetic field. Placing three small loops on the satellite allows each loop to couple to this magnetic field, producing three combinations of force and torque.

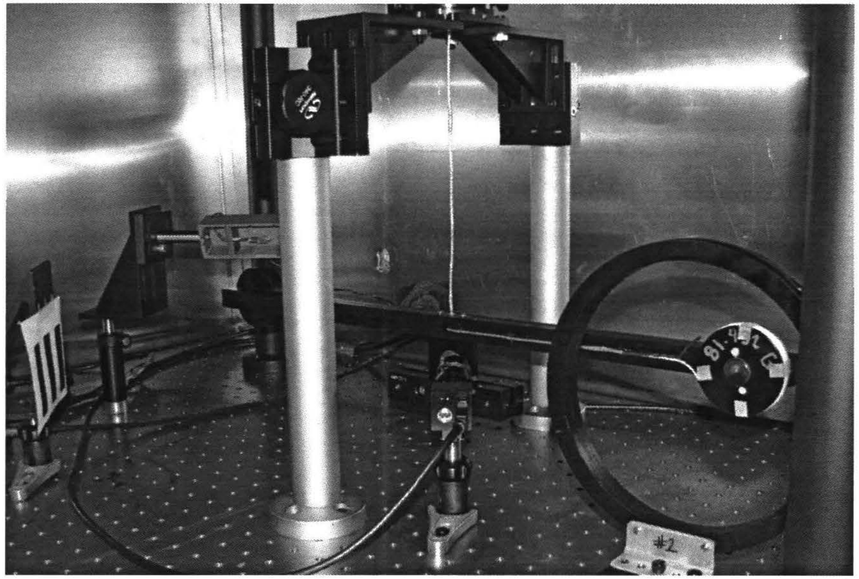
By adding two more large loops as shown, each running at a different frequency, the satellite can now generate 9 combinations of force and torque—enough to both position itself and orient itself in space.



4F: Force Field Formation Flying

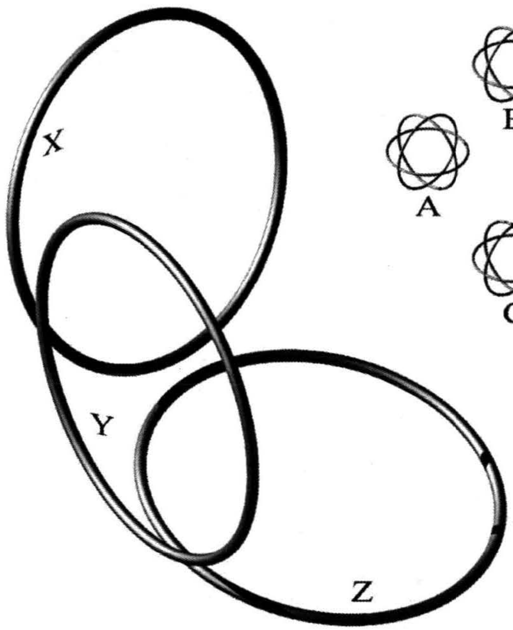


A small coil was suspended between two large drive coils to demonstrate alternating magnetic field induced torque.

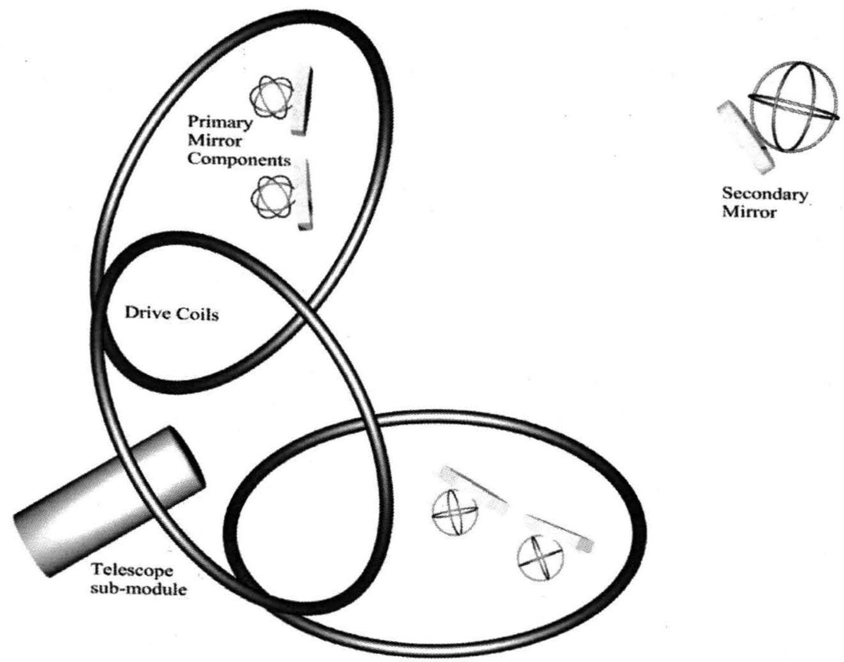


A torsion balance was used to measure the phase variations in force between a large drive coil and a small satellite coil.

Satellite Formation Flying: Propelling, Tracking, and Powering



Multiple satellites can position and orient themselves in space. This should allow the creation of a next generation space telescope with free floating mirrors that allow adjustment and expansion of the telescope (including changing the pointing direction).



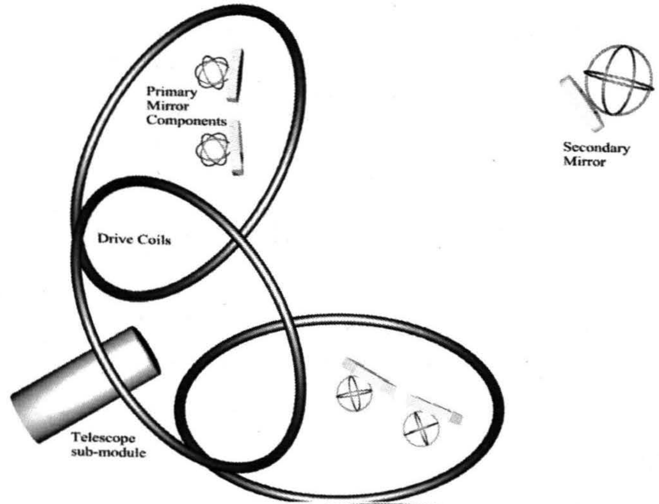
We have a publication on this topic, which describes the theory and a laboratory demonstration, in the March Issue of Acta Astronautica.

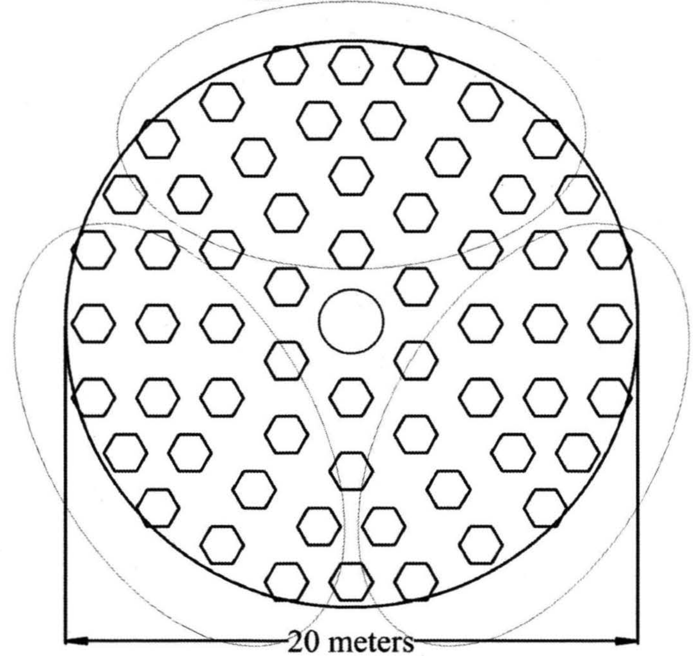
Satellite Formation Flying: Propelling, Tracking, and Powering

So by utilizing coupled coil concepts we believe we can generate forces on free flying satellites, determine their positions, and deliver power to them.

This would be an novel concept that is technically credible and could be implemented inexpensively in a demonstration satellite.

This concept provides both forces and position feedback allowing the accurate positioning and orientation of a large number of satellites, a technology that no other approach we have seen comes close to meeting.





Thank you

Stanley Starr
MS NE-L5
321-867-2262