CubeSat with Nanostructured Sensing Instrumentation for Planetary Exploration

Joseph Wang
University of Southern California

Swomitra Mohanty, Mano Misra, Tatiana Jevremovic
University of Utah

Graduate Students:
Travis King, Steven Burnham, University of Utah
William Yu, Brain Franz, University of Southern California

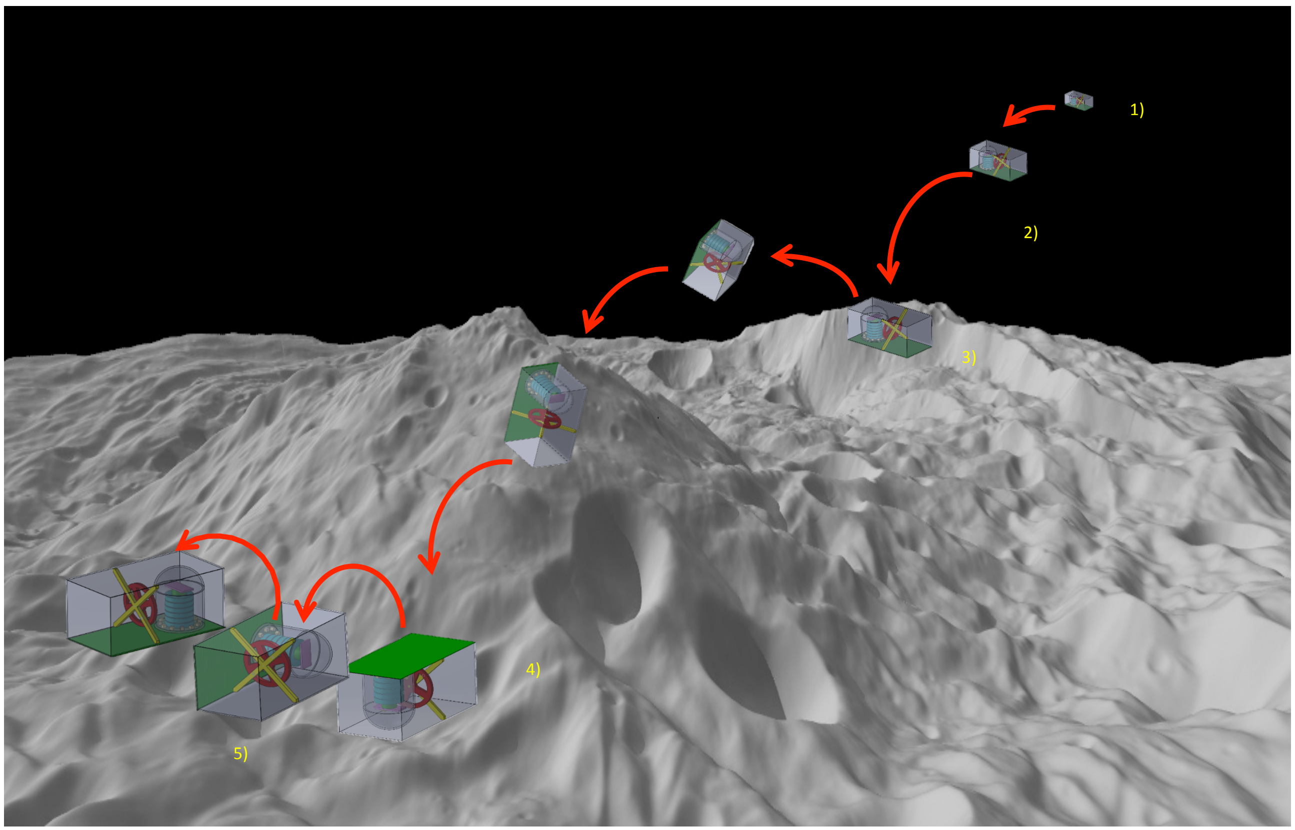
Contact: josephjw@usc.edu

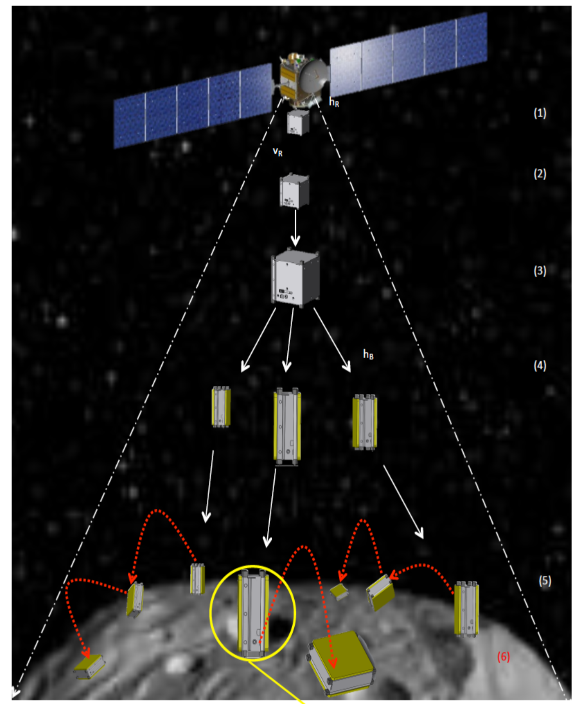
Introduction

Motivation: Few low cost options currently exist in situ exploration of small asteroids and comets

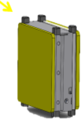
Challenges: Driven by the requirements of science instrument, which dictate the size, mass, power, cost, of spacecraft

Potential solution (?): new nanosensor based instruments delivered by low cost CubeSat lander





(1)	Spacecraft Hover @ h_R
(2)	Lander Release @ v_R
(3)	Uncontrolled Descent
(4)	Break Into Sub-1U Landers @ h_B*
(5)	Landers Impact @ v_I=v_R
(6)	Rebound**



Yellow surfaces represent adhesive landing mechanisms to minimize the rebound effect of impact

- **Objective:** investigate the feasibility of
  - developing a new, nano-sensor for miniature instruments for surface composition analysis
  - designing a CubeSat based lander to deliver the instrument to asteroids/comets

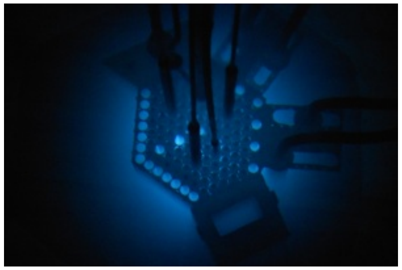
- **Outline:**
  - Background
  - Sensor and Instrument Study
  - Spacecraft and Mission Design
  - Summary and Future Work

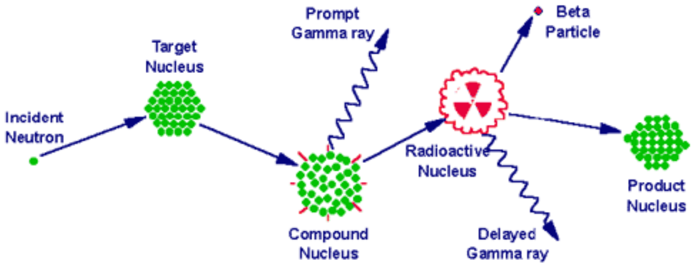
Background

- **Gamma-Ray/Neutron Spectrometer:**
  - cosmic rays bombard airless body surface
  - excites nuclei -> gamma-ray and/or neutron emission
  - standard remote sensing technique in planetary exploration
  - state-of-art:

    GRaND on DAWN: 10kg, 15W, 25cmX18cmX26cm (~12U)

    detects O, Mg, Si, Al, Ca, Ti, Fe, H, C, N, Cl.
- **Neutron Activation Analysis (NAA):**
  - neutrons from neutron source bombard surface
  - natural isotopes -> radioactive isotopes -> gamma ray emission
  - a non-destructive element analysis technique widely used on earth (archaeology, geology/mining, soil science)
  - NAA may detect up to 74 elements in ppb but is a “facility” rather than an “instrument”





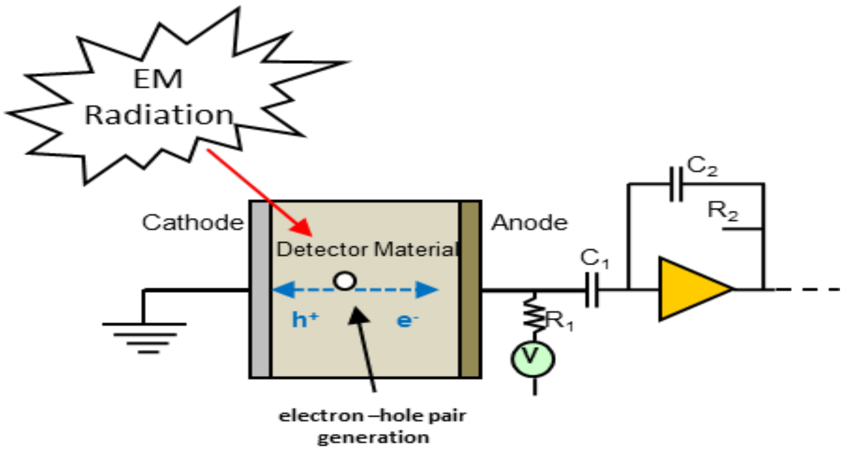
- **Gamma ray detector is the key component in either Gamma Ray Spectrometer or NAA**

  detect gamma rays at energy levels related to element concentration

- Conventional sensors: gas ionization, scintillation, semiconductor
- Semiconductor type sensor has shown superior energy resolution as compared to scintillation.

Cadmium Zinc Telluride (CZT) is a candidate material for next generation of radiation sensor for low to medimum energy gamma ray

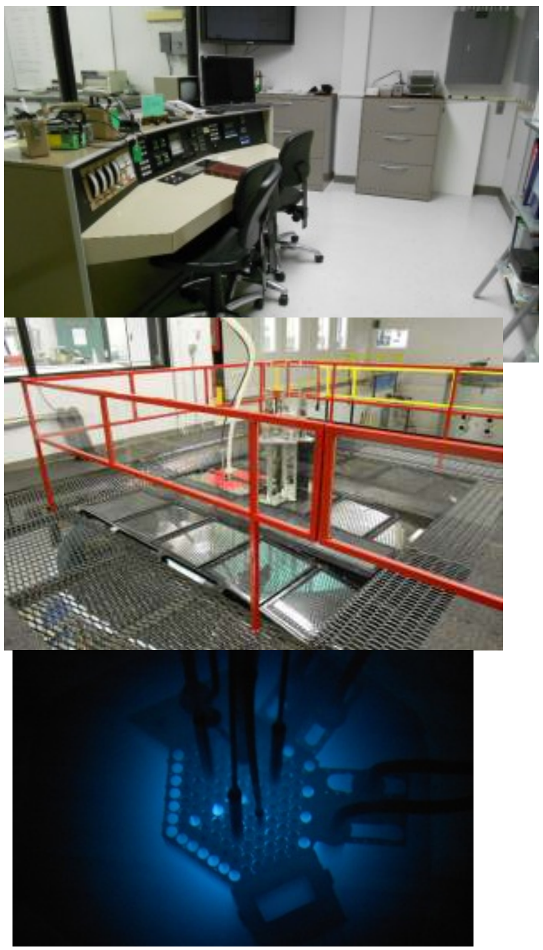
large band gap (1.56eV)
high density (5.78g/cm^3)
high energy for electron-hole production (4.64eV)
high resistivity (1E10ohm-cm)
higher threshold for radiation damage



Schematic illustration of the working principle of a nuclear detector with single element planar configuration.

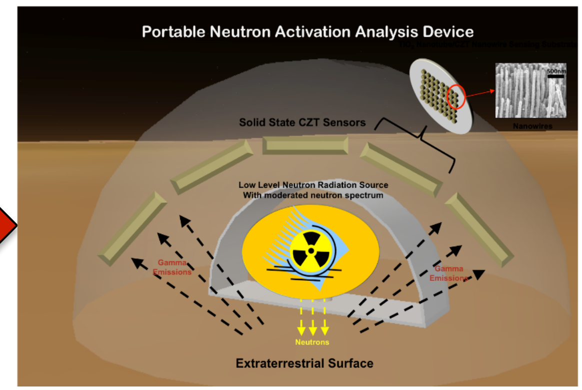
Sensor and Instrument Study

- **Objective:** to study the feasibility of utilizing nanowire sensors for miniature gamma-ray/neutron spectrometer and in-space applications of NAA
  - significant reduction in mass, size, and power from state-of-the-art



Challenges

?

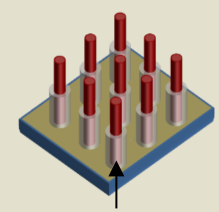


Neutron Sources

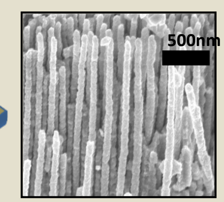
Electronics

Instrument Design

Sensors



CZT Nanowire Array Schematic



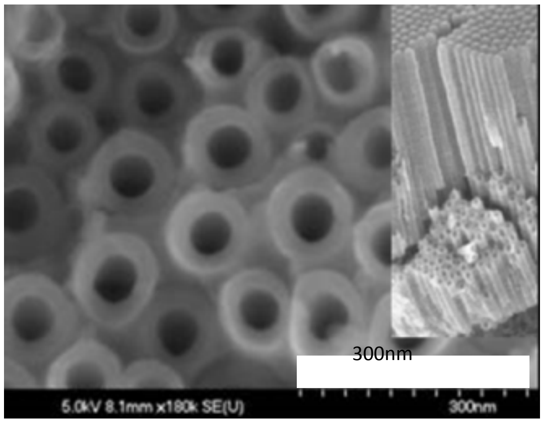
SEM of CdTe Nanowire Array

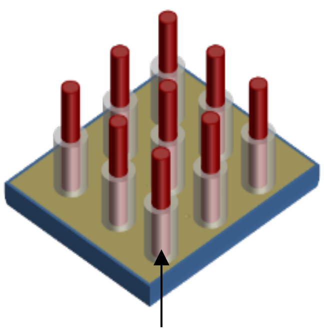
NIAC Phase 1 Sensor/Instrument Study

- **Design requirements/criteria for instrument:**
  - Simple/autonomous operation: no sample collection/preparation
  - Efficiency/Sensitivity
  - ***Integration with CubeSat: miniature size, low mass/power/cost***

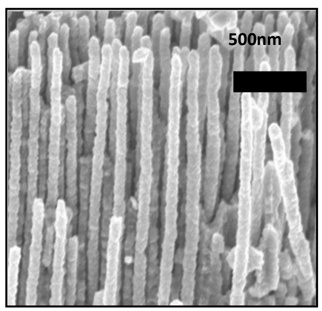
- NIAC Phase 1 studied the following:
  - Selection of semiconductor material for sensor(CdZnTe)
  - Nanowire fabrication (TiO_2 nanotubes used to form CZT nanowires)
  - Detector efficiency/sensitivity/noise suppression
  - Portable neutron source
  - Electronics
  - Power supply (Battery by Clyde Space CubeSat Sys)
  - Preliminary shielding consideration
  - Component selection

Stacked Arrays of CZT Nanowire Sensor





CZT Nanowire Array Schematic



SEM of CdTe Nanowire Array

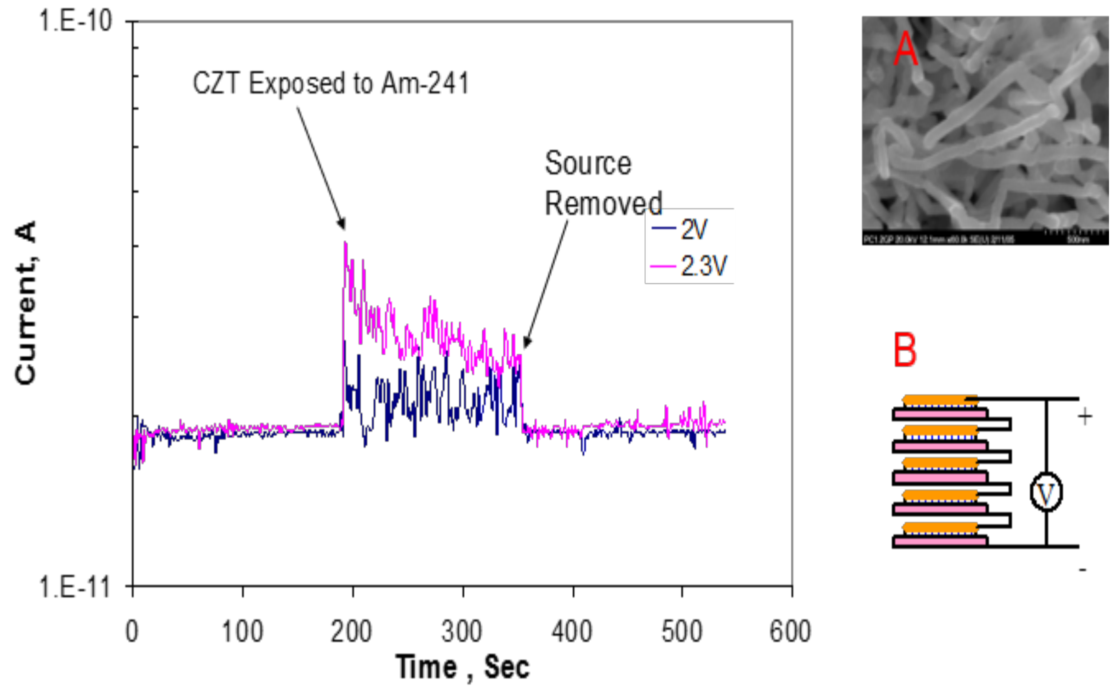
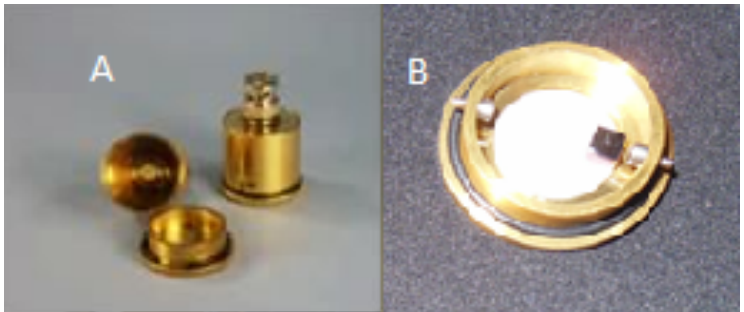


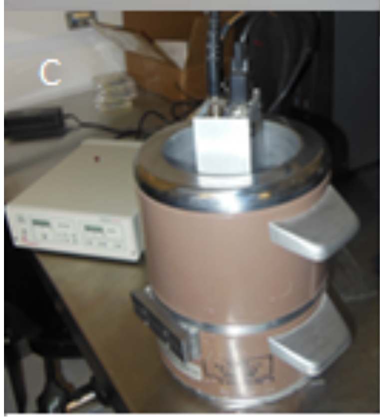
Figure 5. Radiation sensing of CZT nanowires exposed to 4μCi radiation with Am-241 source. The insets are (A) CZT nanowire SEM image and (B) schematic of stacked CZT templates ([37])

TiO_2 nanotube/CZT nanowire

Sensing response of 5 stacked arrays of CZT nanowire sensor

Desktop NAA Instrument Using CZT Crystal



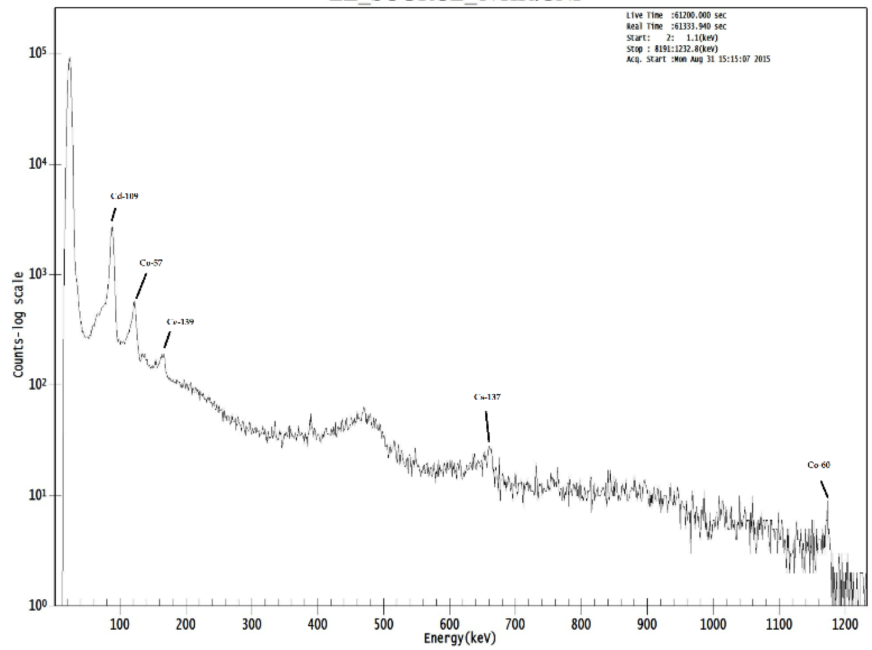


A. eV Products Inc. eV-480 test fixture

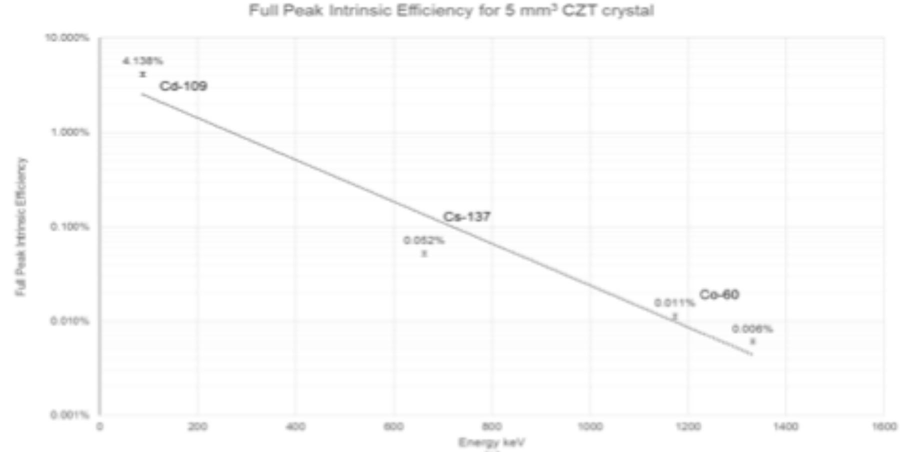
B. 5x5x5 mm CZT crystal

C. Canberra DSA-1000 and eV-550 charge sensitive preamplifier

Figure II.5. Equipment setup for spectrometer grade 5 mm^3 planar CZT crystal from eV Products Inc.



Example of measured gamma-ray spectrum



Intrinsic effeciency

Sensor/Instrument Study Conclusion

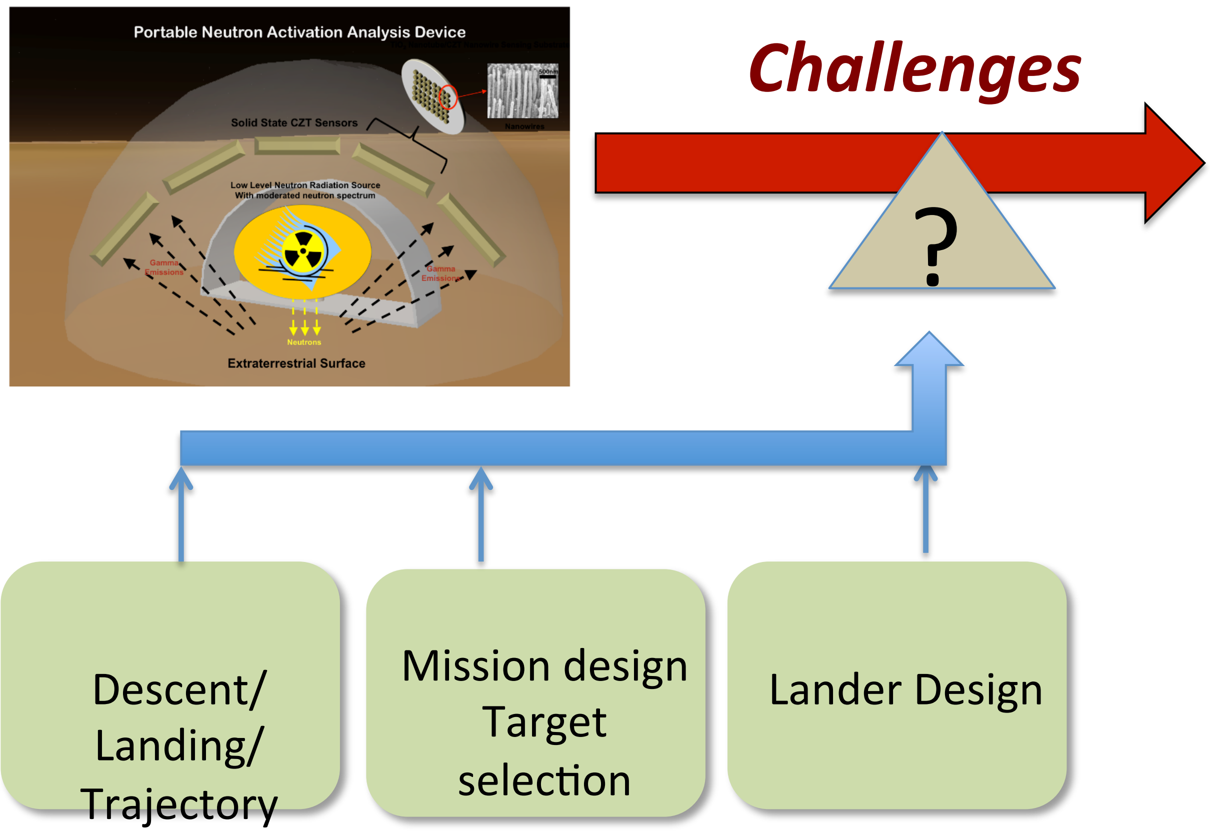
- The CZT nanowire array sensor can be applied to develop miniature instruments for surface composition analysis
  - miniature gamma-ray spectrometer (remote sensing or in situ)
  - coated with neutron converting material (^{10}B, ^{6}Li, etc): miniature neutron spectrometer (remote sensing or in situ)
  - combined with portable neutron source: miniature NAA (in situ)
- Estimated size, mass, and power of the instrument:

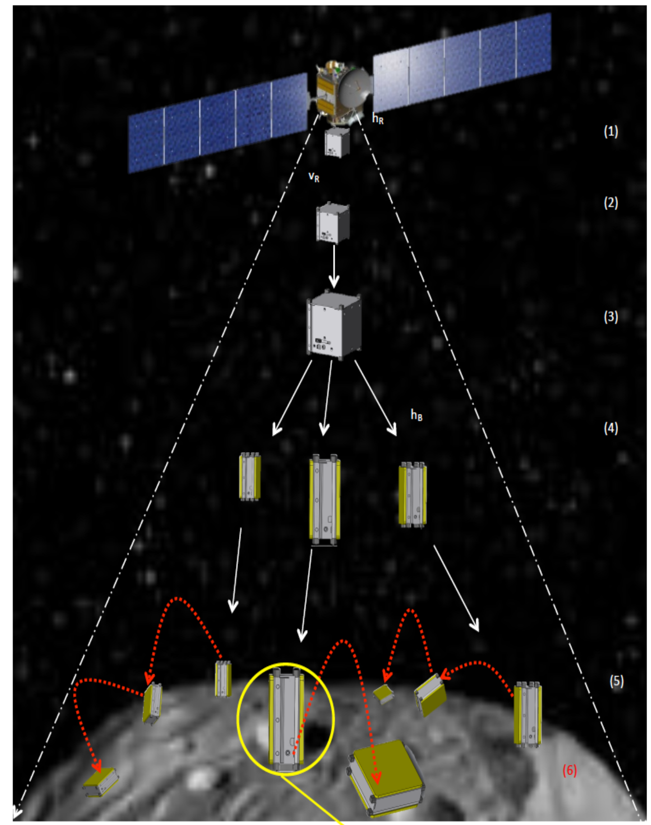
  <1/2U; ~150 to 200g, ~200-500mW
- Such instrument can fit into a CubeSat bus and used as in situ instrument (more accurate, shorter operation time, less radiation effect)

- Challenges and future work
  - Sensor efficiency/sensitivity (further modeling, sensor design)
  - Noise interference due to background Campton scattering (anti-coincidence method and fuzzy logic algorithm to suppress Compton scattering)
  - Flight grade miniature electronics
  - For NAA instrument: portable neutron source

Spacecraft/Mission Design

- **Objective:** to study the feasibility of developing low cost cubesat based instrument lander for in situ analysis at small asteroids/comets
  - significant reduction in mass and complexity from state-of-the-art





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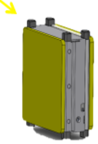


Yellow surfaces represent adhesive landing mechanisms to minimize the rebound effect of impact

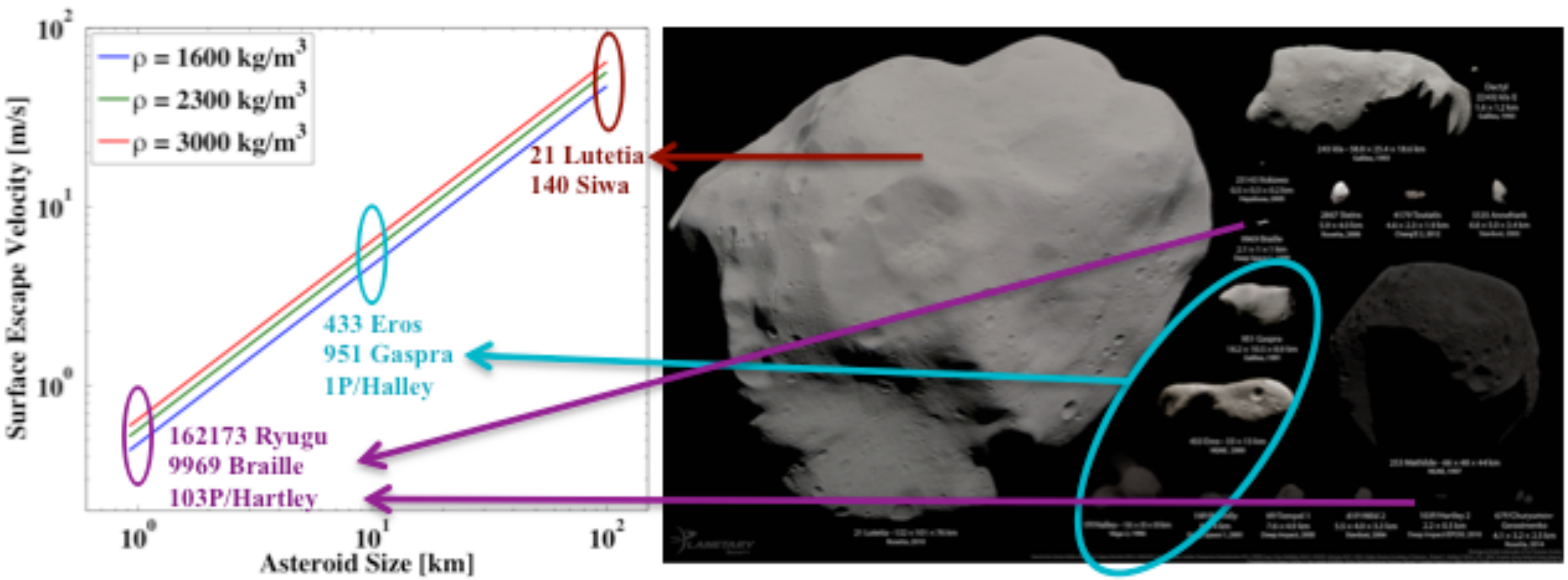
NIAC Phase 1 Spacecraft/Mission Design

- **Applications to small asteroid/comet missions:**
  - For certain small asteroids/comets, the new miniature instrument would enable the development of CubeSat sized lander for ground truth analysis
  - Potential mission scenario:
    - Single, multiple, or swarm of low cost, expandable landers

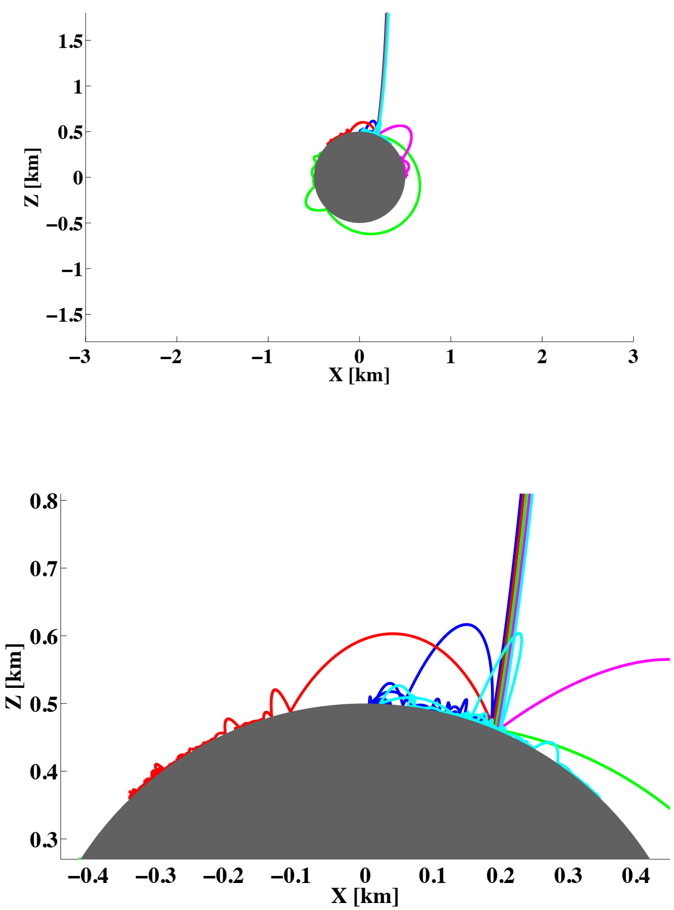
- **Design Objectives:**
  - Mass/power/size/trajectory constrains imposed by mission
  - CubeSat based platform
  - Uncontrolled descent; no active propulsion
  - Self-landing/Self-orienting

Mission Applicability/Constrains

- Feasibility is sensitively influenced by asteroid properties, surface interaction, and mother spacecraft trajectory
  - Asteroid size, mass, shape
  - Surface interaction; Coefficient of restitution
  - Initial lander release velocity and altitude



Uncontrolled Descent/Hopping Landing: 1 km Asteroid

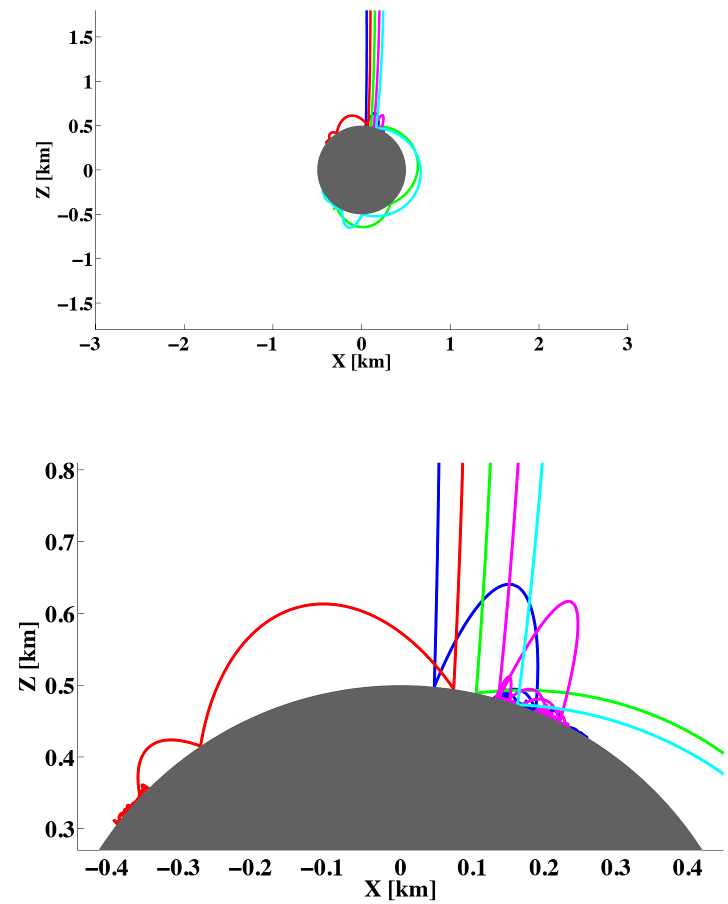


$V_0 = .0047$ m/s, $h_0 = 10$ km

Density: 1600 kg/m^3

CoR: 0.5

V_{esc}: 0.47 m/s



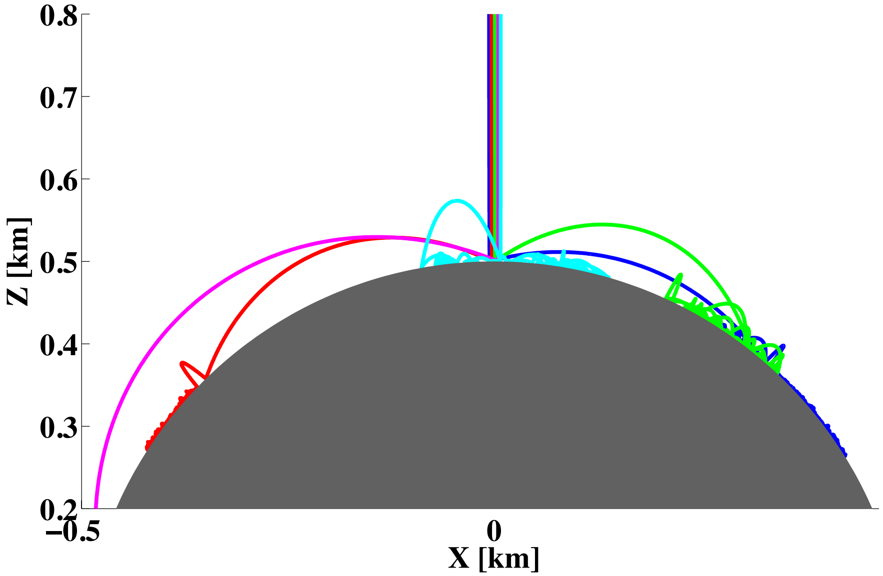
$V_0 = .047$ m/s, $h_0 = 10$ km

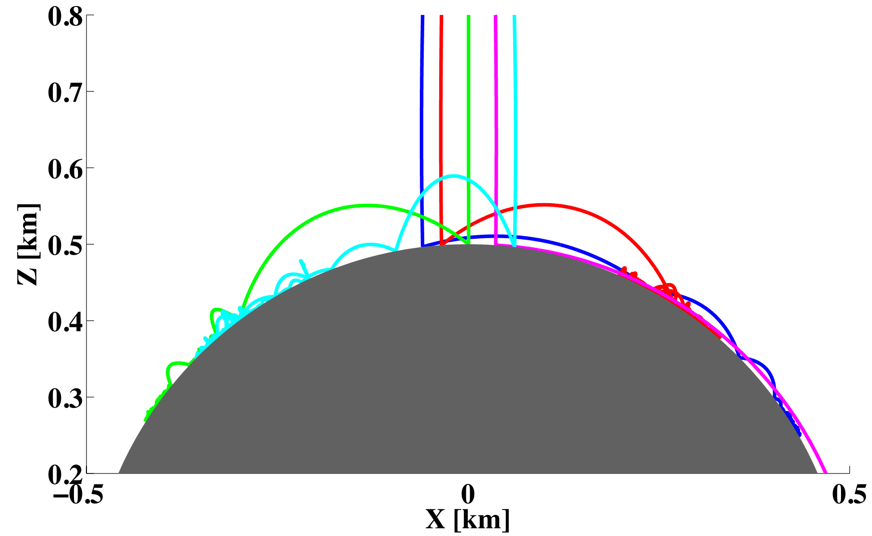
Density: 1600 kg/m^3

CoR: 0.5

V_{esc}: 0.47 m/s

Uncontrolled Descent/Hopping Landing: 1 km Asteroid





V_0 = .0047 m/s, h_0 = 1 km

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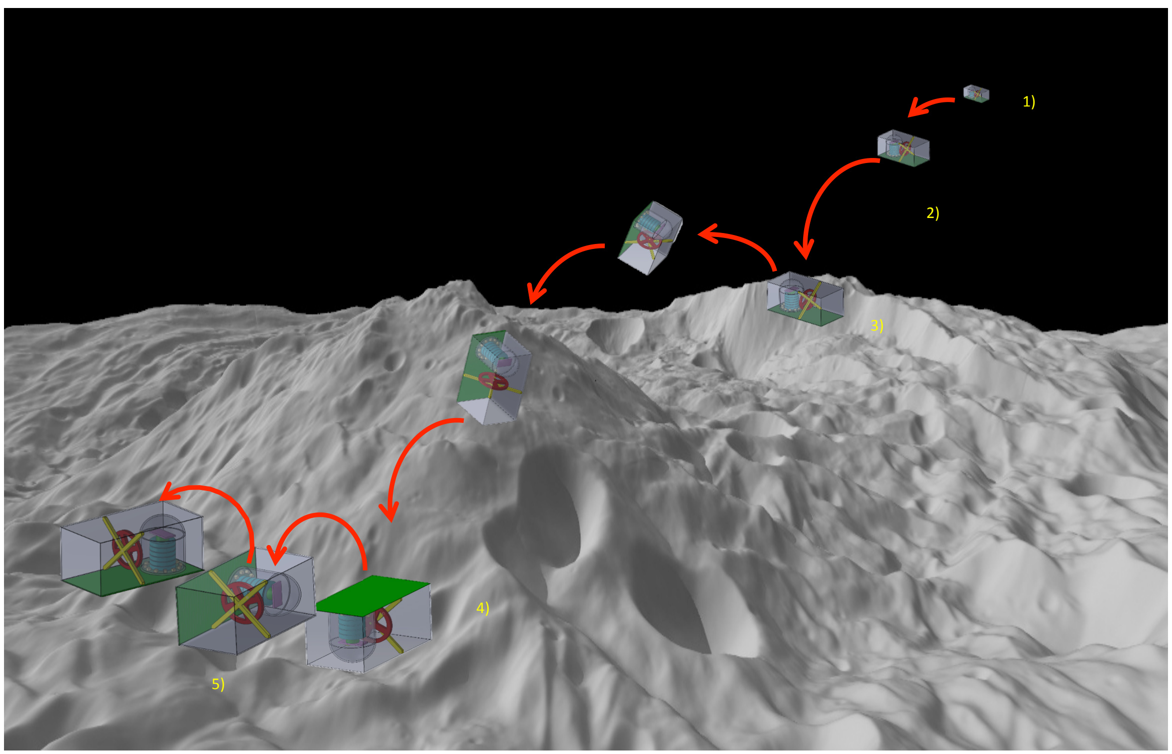
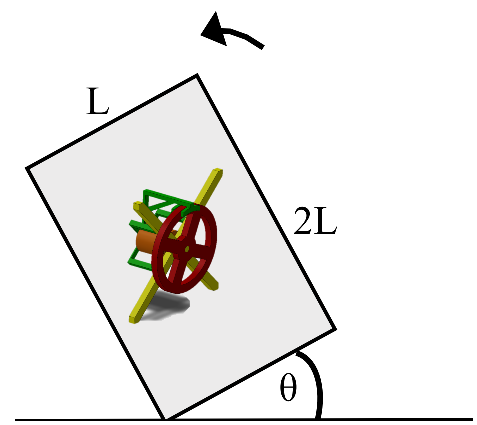
Preliminary Instrument Lander Design

- Based on existing CubeSat platform
- Baseline design:
  - 3-axis stabilized or spin stabilized: ~2U, ~1.5kg, ~3.5W (without ADCS: ~1U, ~0.8kg, ~1.5W)
  - No propulsion (self-landing)





Mission/Spacecraft Design Conclusion

- It seems feasible to design a CubeSat based low cost instrument lander to deliver the proposed new instrument to small asteroids/comets
  - Single, multiple, or swarm of expandable landers
    - Low mass: ~1.5kg
    - Low power: ~1.5W to 3.5W
    - Small size: ~2U
    - Disposable

Both the instrument and lander concept represent significant reduction in mass, size, power, cost from the current approach.

It seems feasible to develop low cost missions utilizing nano-sensor instrumentation and CubeSat lander for in situ exploration at small asteroids/comets