Micro Asteroid Prospector Powered by Energetic Radioisotopes: MAPPER

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Topics Presented

- Goals and objectives
- Target characterization- Main Belt Asteroids
- Sub-Systems
- Preliminary optimization calculations
- Issues
- Conclusions

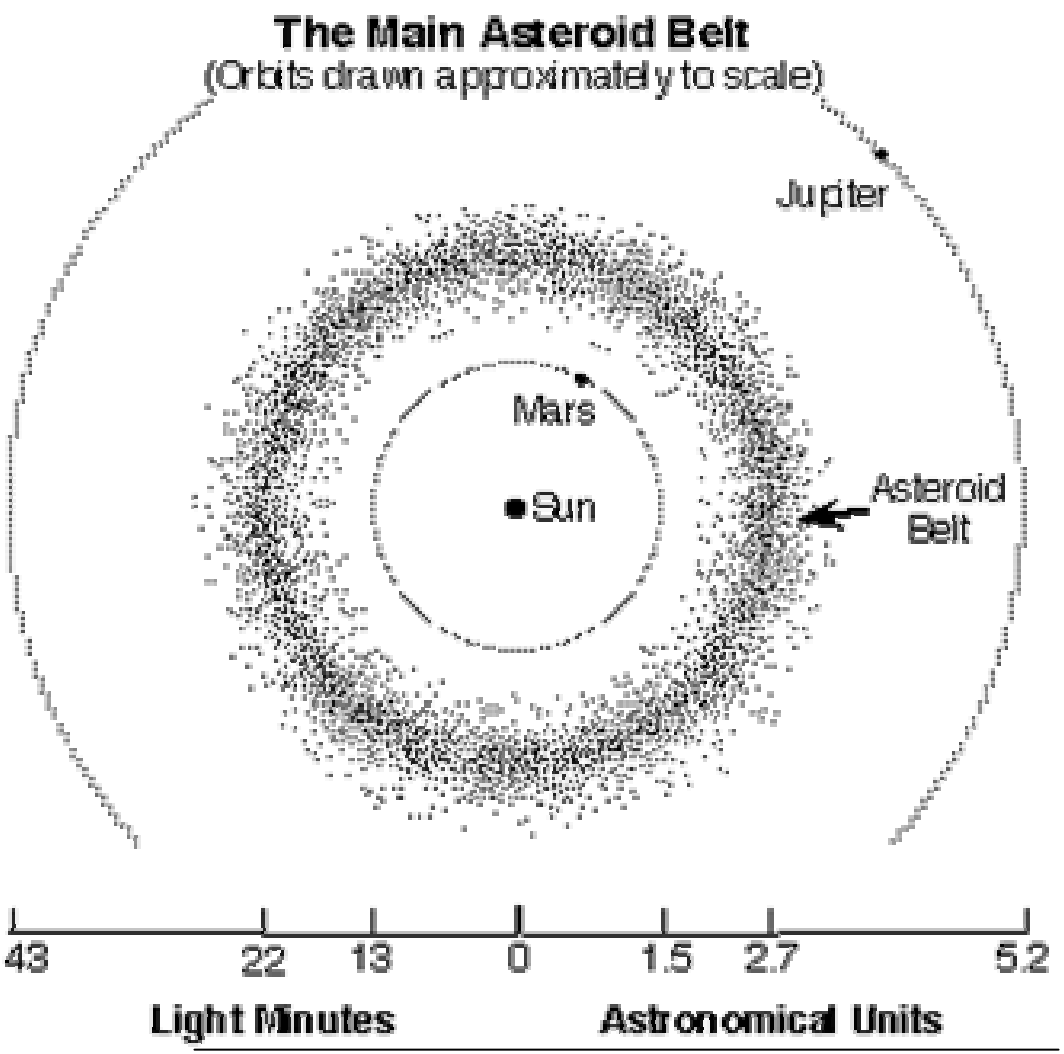
Goals and Objectives

- Purpose: Catalogue the resources of the Main Belt asteroids for future exploration
- Goal: Design a light-weight, in-expensive spacecraft so that a fleet can cruise autonomously through the Belt for 20 years
- Objectives:
  - Determine mass, power, and number of spacecraft for characterizing a significant fraction of the Main Belt asteroids
  - Identify major issues and future goals

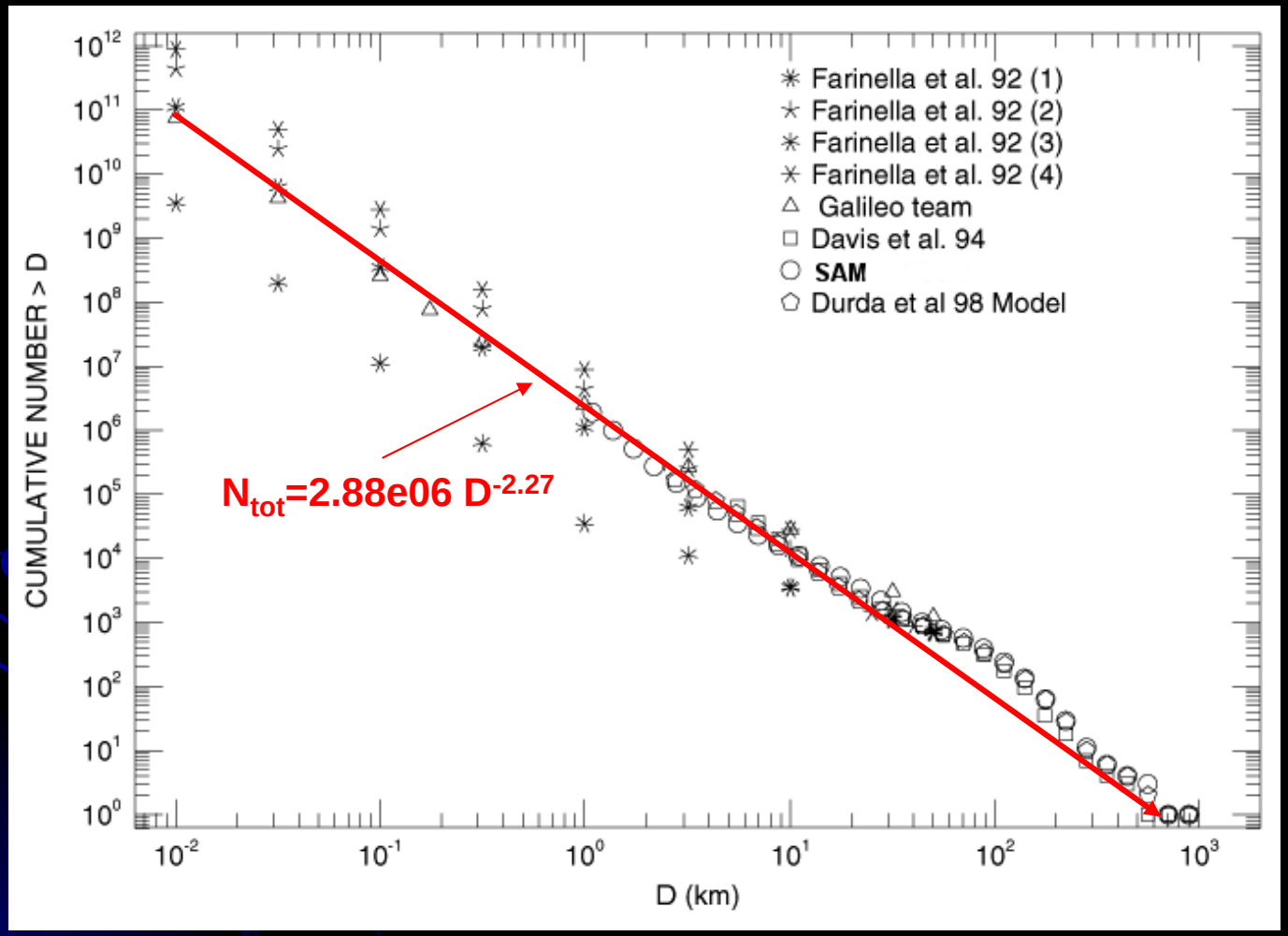
Main Belt Asteroids

- The Asteroid Belt may be the most valuable future resource in the solar system
- The asteroid belt is estimated to contain 100 billion objects.
- The total mass is calculated to be around 1/1000 of Earth's mass - equivalent to breaking the top 1.3 miles of the Earth's crust into pieces
- Diameters range from a few kilometers to a few meters
- Most of the asteroids are silicon dioxide, some are iron and other metals, a lesser number are carbonaceous chondrites with up to 10 % water by weight, and a few may be heavy precious metals.
- Average separation distance is 2.3×10^4 km for Dmin=20m

The Main Belt spans the range between 2.2 and 3.7 AU

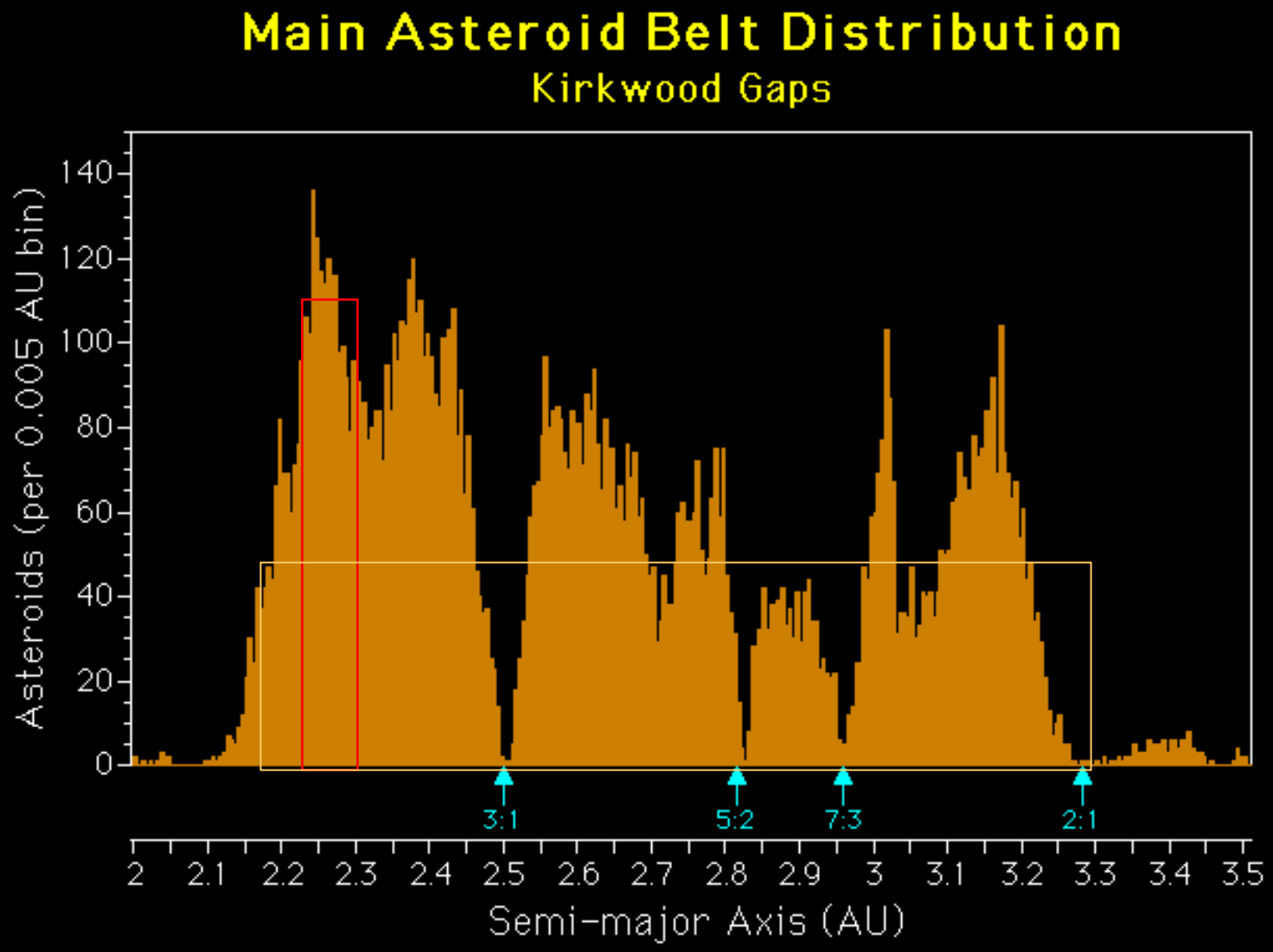


The main belt asteroid size-frequency distribution approximately follows a power law



(Adapted from Farinella and Davis, 1994)

The asteroids in the belt are not uniformly distributed but form bands



Subsystems

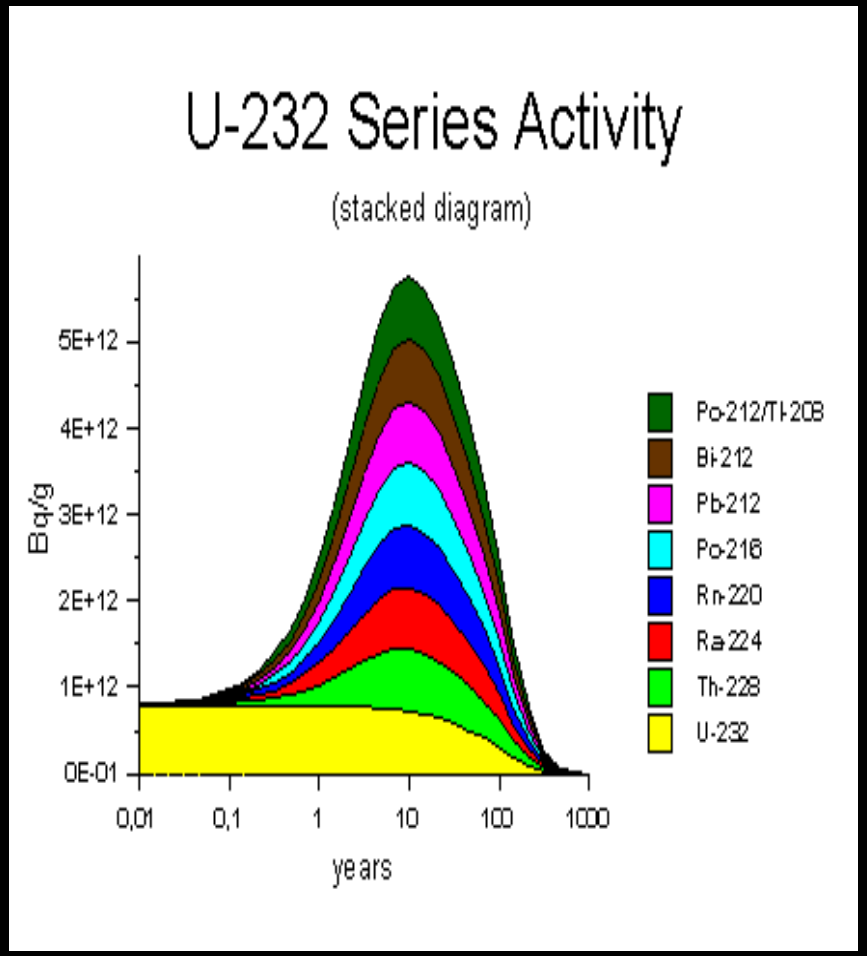
The MAPPER concept requires the integration of many subsystems

- A power supply to provide electrical power to a platform that can propulsively cruise between targets
- A radiation detector system that can measure elemental constituents at a standoff distance,
- A heating system that can extract and store volatiles for propulsion,
- A tagging method to label the target for future generations.
- A method of absolute coordinate location determination via star tracking or inter-communication with Earth or a fixed beacon.
- Radar system sufficient to provide guidance to the next target and avoidance of smaller objects
- A communication link to Earth

POWER

^{232}U offers high specific power

- The decay sequence of ^{232}U releases 25% of the energy per atom of a nuclear reactor but requires no critical mass
- 5 W(th)/g peak is 10 times Pu238
- Power scales linearly with mass
- Relatively flat over 20 year period
- Production:
  - Available in spent fuel
  - Fast neutron irradiate U-233
  - Accelerator irradiate Th-232
- Uses tuned PV conversion
- High gamma activity requires standoff from platform
- ISSUE: lifetime of tuned PV



Preliminary estimates of power source activity (3e04 Ci) are well below past launch history for the US

NASA and DOE have successfully launched 25 nuclear power sources into space

Spacecraft	Launch	Curies of Pu
Transit 4A,4B	1961	1,500
Transit 5BN-1,2,3	1963	17,000
Nimbus B1, III	1968, 69	35,000
Apollo 12,13,14, 15,16,17	1969-72	44,500
Pioneer 10,11	1972, 73	80,000
Transit	1972	24,000
Viking 1,2	1975	41,000
LES 8,9 (GEO)	1976	159,000
Voyager 1,2	1977	240,000
Galileo	1989	264,400
Ulysses	1990	132,500
Cassini	1997	400,000

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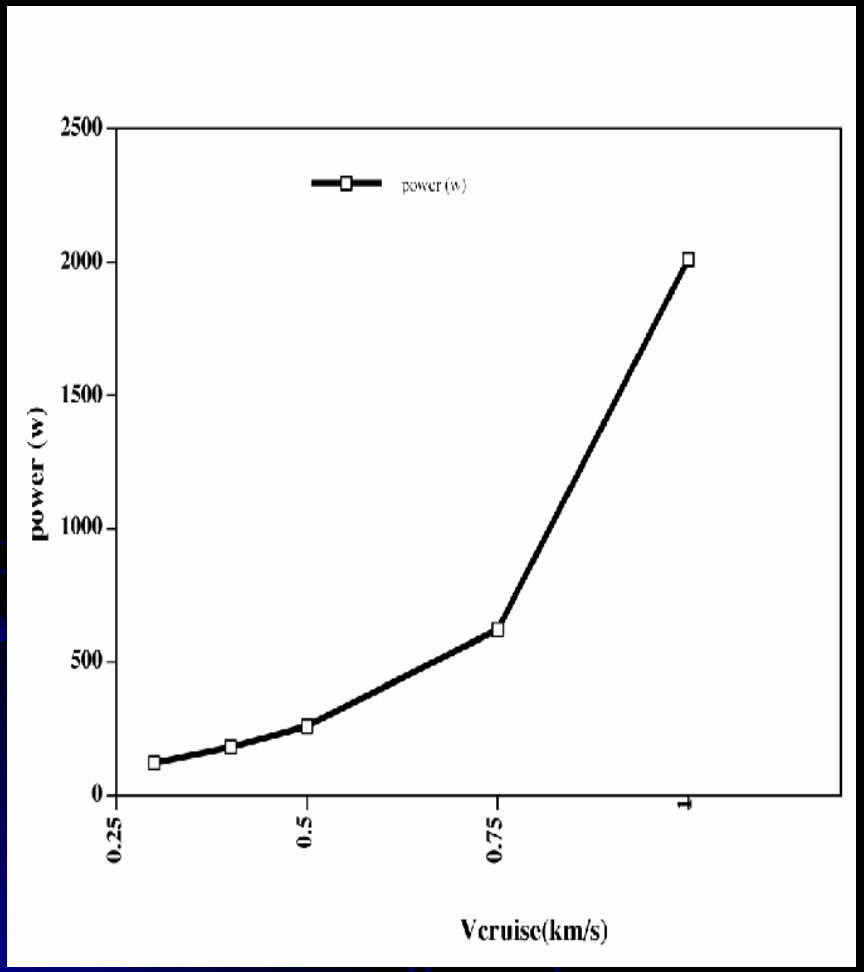
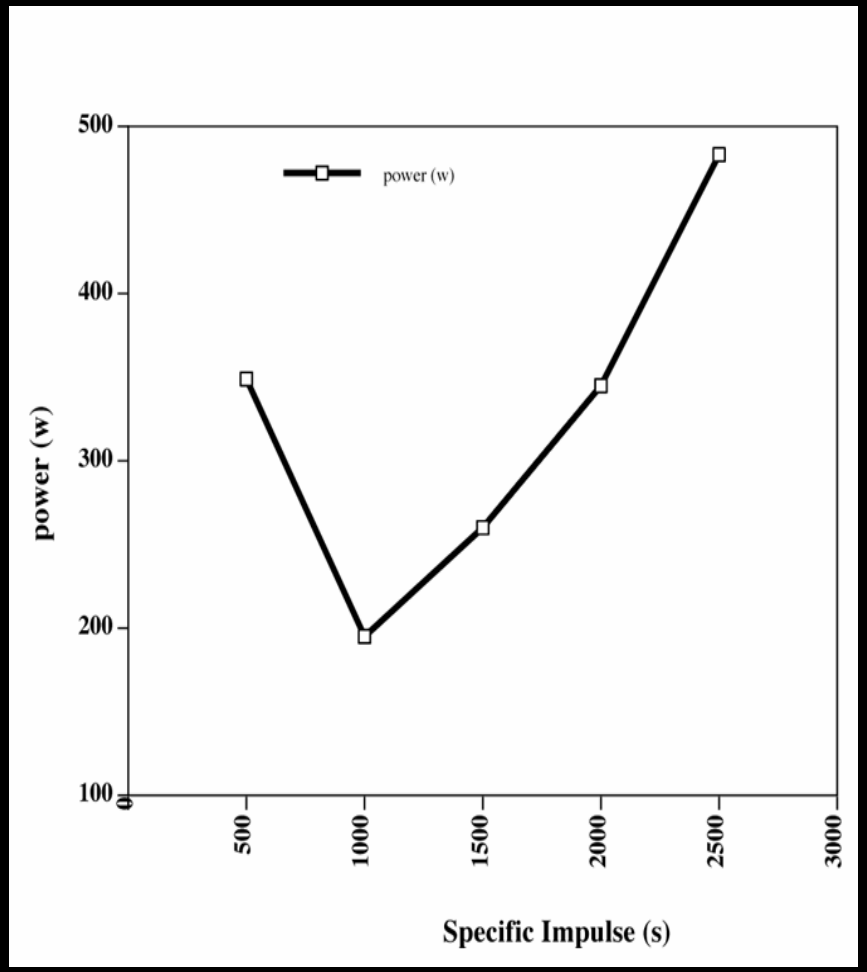
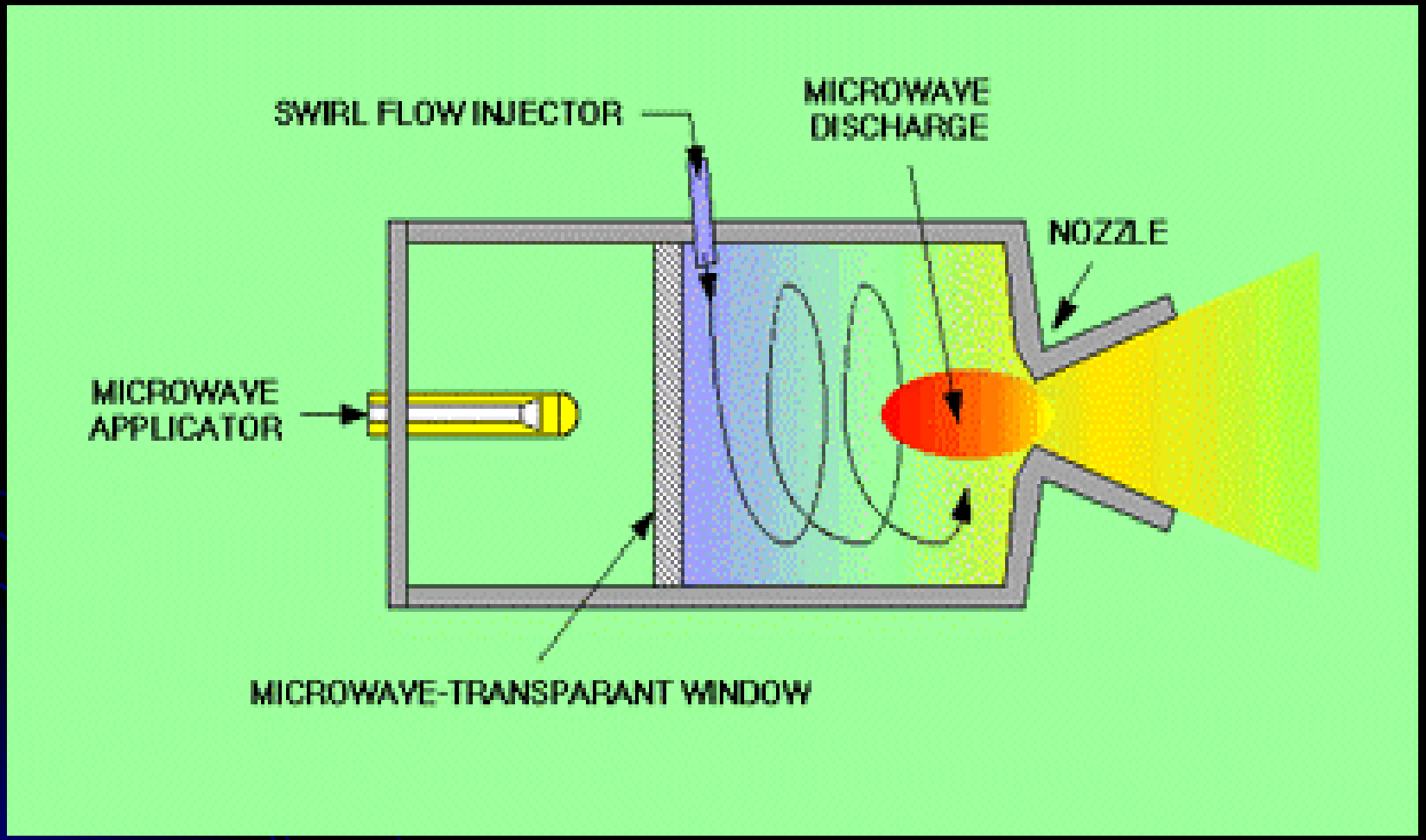
Power levels and mass of the power system vary strongly with average cruise velocity and Isp





PROPULSION

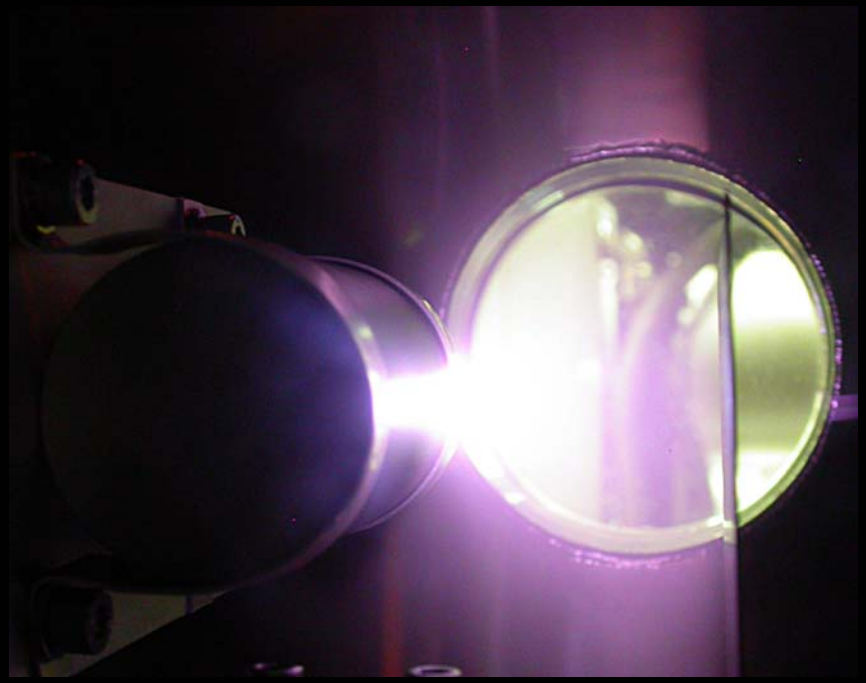
Microwave driven thrusters offer the potential of long life due to low surface interactions



(courtesy of http://www.islandone.org/APC/Electric/04.html)

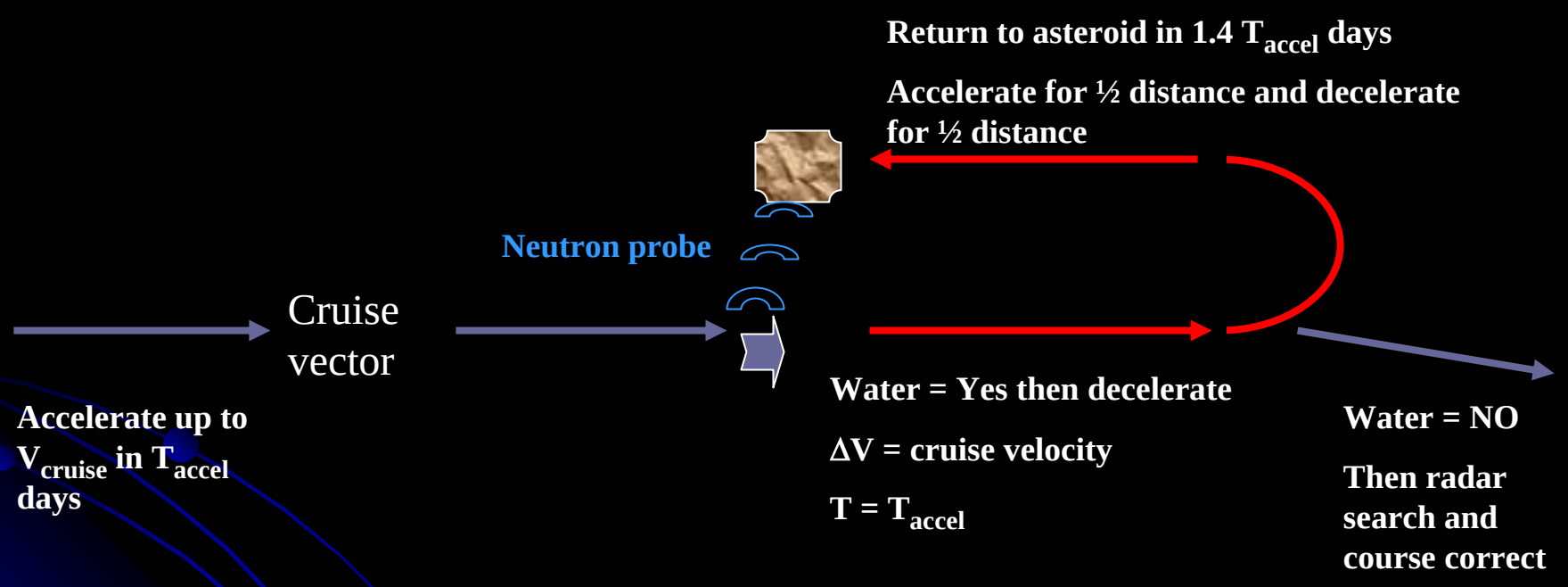
Microwave driven electric thrusters provide high Isp and good efficiency

- NASA GRC recently demonstrated a 6000s Isp using a microwave driven thruster with Xe
- GRC and Penn State have demonstrated lower power microwave thrusters using water
- Significant advances in reducing mass and increasing power density are predicted



Refueling

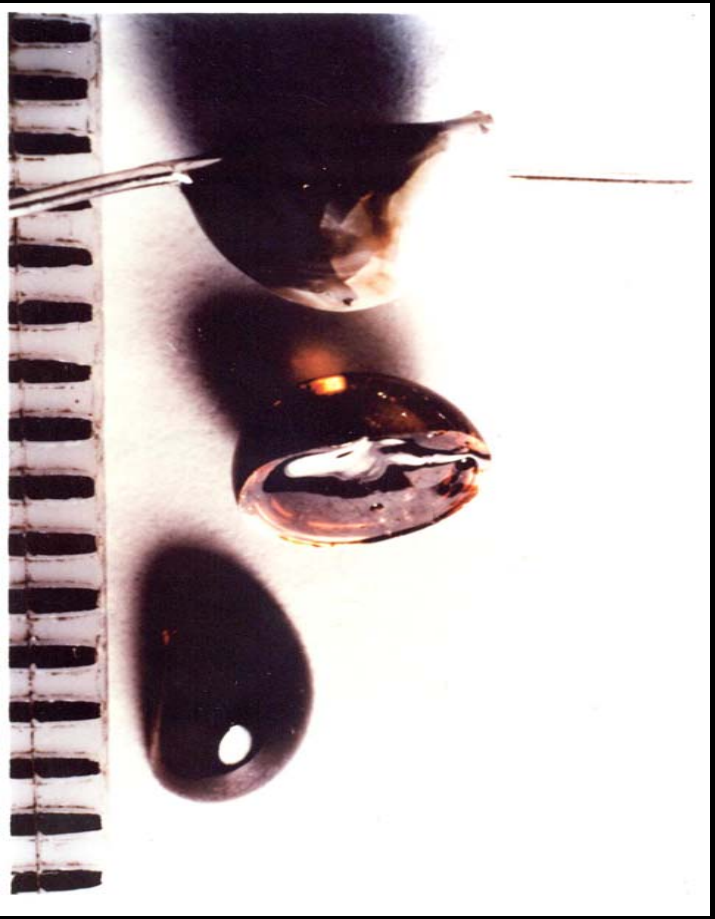
Refueling sequence



Microwaves couple to regolith

- In 1985, Dr. T. Meek of the Los Alamos National Laboratory (LANL) demonstrated the ability to extract water from simulated lunar soil using 2.45 GHZ microwaves.

- According to Meek, using conventional means to heat the soil would require 10,000 times more energy than using the microwaves to selectively heat the water in the soil.



2.45 GHz microwaves for 15 s onto lunar soil sample

The microwave generator for the thruster will also serve as the heating source to extract water from CC asteroids

- 2.45 GHz microwaves will penetrate roughly 30 cm into 10% bearing regolith
- A 50 cm diameter bell will extract 60 kg of water from a 10% CC
- extraction rate is around .025 kg/w-day
- Slight pressure buildup will be countered by operating the thruster at low power
- Water in the fuel tanks will be maintained as liquid using the waste heat transported from the power source, ~160 w required
- Condensed water is transported from the extraction unit to the fuel tank via capillary action

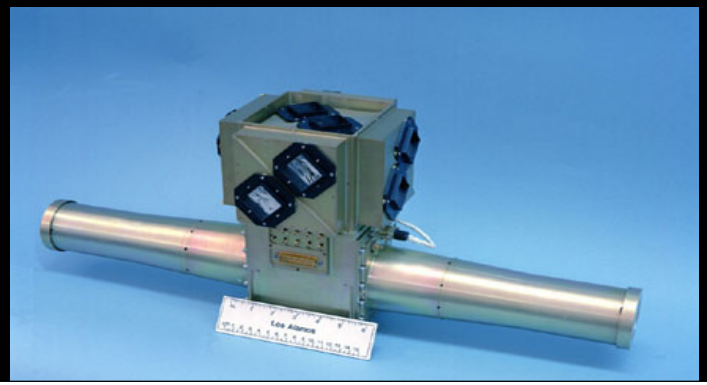
DETECTION

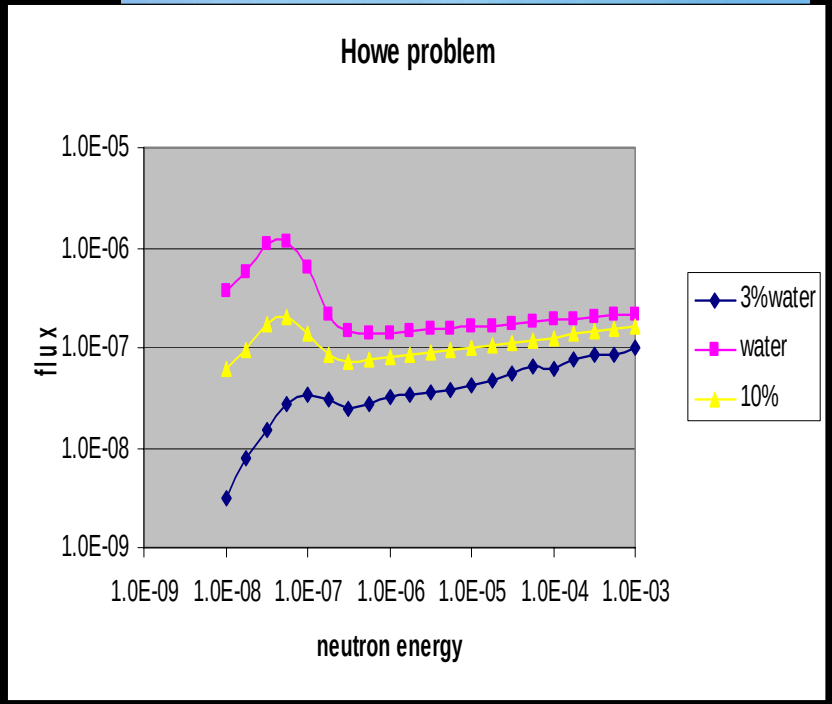
Neutron Source

- Original concept used ^{232}U plus Beryllium to make neutrons via (α,n) reaction
  - 4π source
    - Created too much background
    - Irradiated components
    - Required close approach, i.e. < one diameter
- Propose H(^{6}Li,n) mini accelerator
  - 13.2 MeV ^{6}Li
  - 10° cone of emission
  - Pulsed, intense source fired during flyby closest approach
- Optimum standoff distance is 3 X diameter

Flight qualified neutron detector has been flown to find water on the Moon

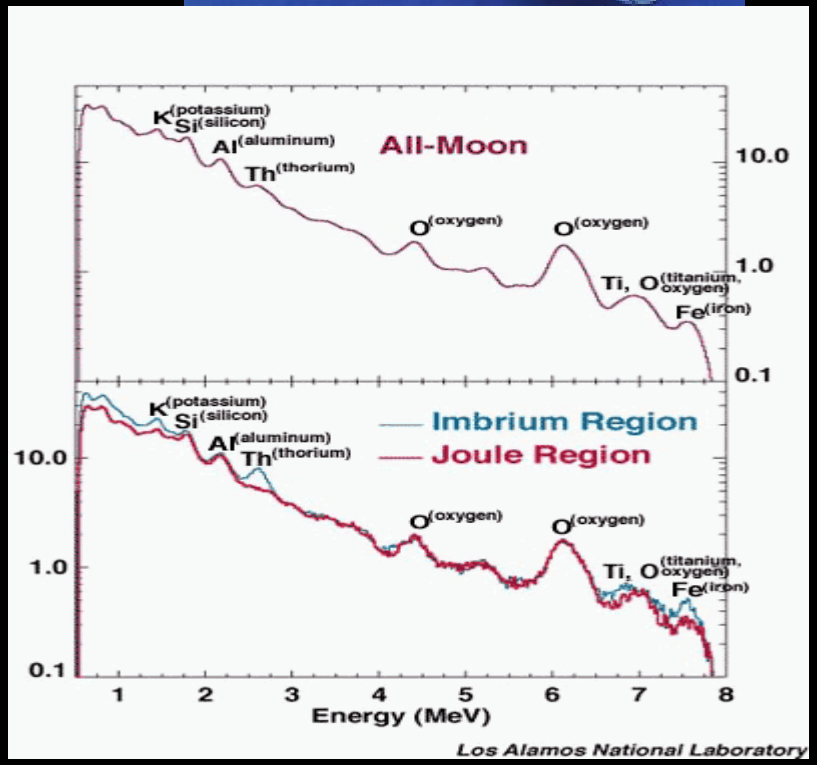
- Designed and built at LANL by W. Feldman
- Weight: 8 lbs
- Electrical power req'd: 3 w
- ^{3}He tubes
- Returned neutron spectrum depends strongly on hydrogen content
- Issue: lifetime





Flight qualified gamma-ray detector has been flown measure gammas on the Moon

- Designed and built at LANL by W. Feldman
- Weight: 3 lbs
- Electrical power req'd: 2 w
- BGO crystals
- Gamma rays identify heavy metals
- CdZnTe or HgI may provide better resolution



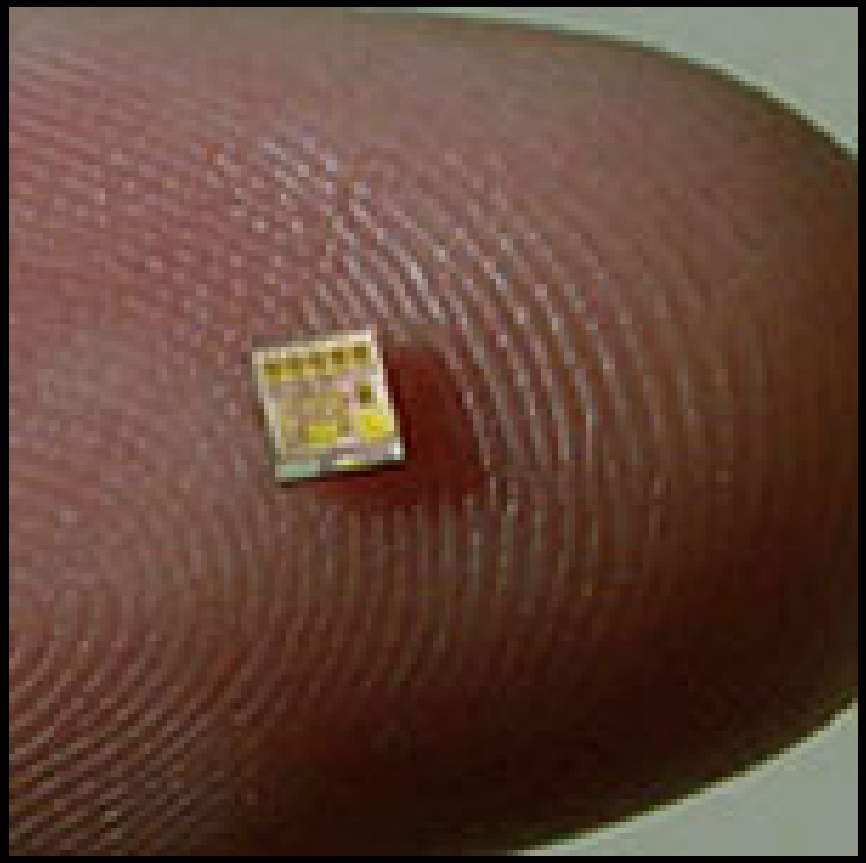
TAGGING and COMMUNICATION

Radioisotope tagging

- Carry 100g samples of 5 isotopes
- T1/2 greater than 30 yrs
- Auto-mixer to randomly mix different amounts of each
- Gives passive gamma ray signal with unique spectrum
- Pro – no power needed
- Pro – long lived
- Pro -- secure
- Con -- Natural background may interfere
- Con --Must be in line of sight to register

“Smart Dust” sensors developed at Berkeley low mass and long life

- Pro –
  - Low mass
  - Broadcast widely, i.e. 4π
  - Reasonable range
- Con-
  - Power needed
  - Less secure
  - Limited life
  - Radiation may degrade



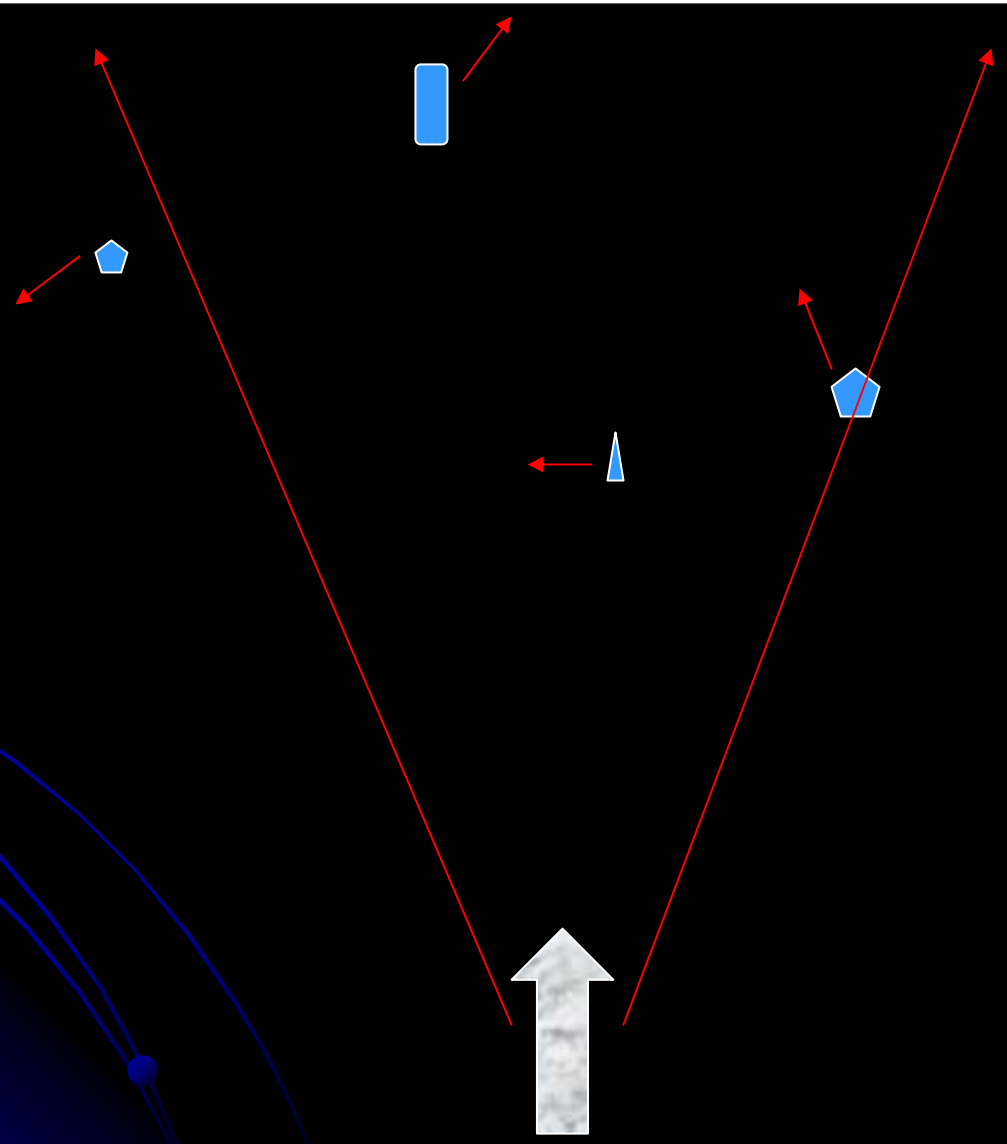
(courtesy of http://robotics.eecs.berkeley.edu/~pister/SmartDust/)

Communications back to Earth rely on demonstrated technologies

- Galileo transmissions required 400 w on board power
- Platform will determine location from “split field of view star sensors (StarNav II) [http://www.jsc.nasa.gov/aiaa/lal/lljun01/] “
- Information burst will include location, measured gamma-ray and neutron spectra, and ship status data

GUIDANCE

The architecture depends on the average velocity of the craft – i.e. cone of acceptability



A light weight radar is required but does not yet exist

- Needs to see 156,000 km out
- Correlate distance with return signal strength (RSS) and target size
- Indicate water content (i.e. albedo) with RSS
- Determine relative velocity with multiple returns
- May require power accumulator to operate in high-power but pulsed mode
- Determines required delta-V
- Enables target choice
- Issues:
  - baseline needed for Synthetic Aperture Radar ?
  - power level?

Optimization

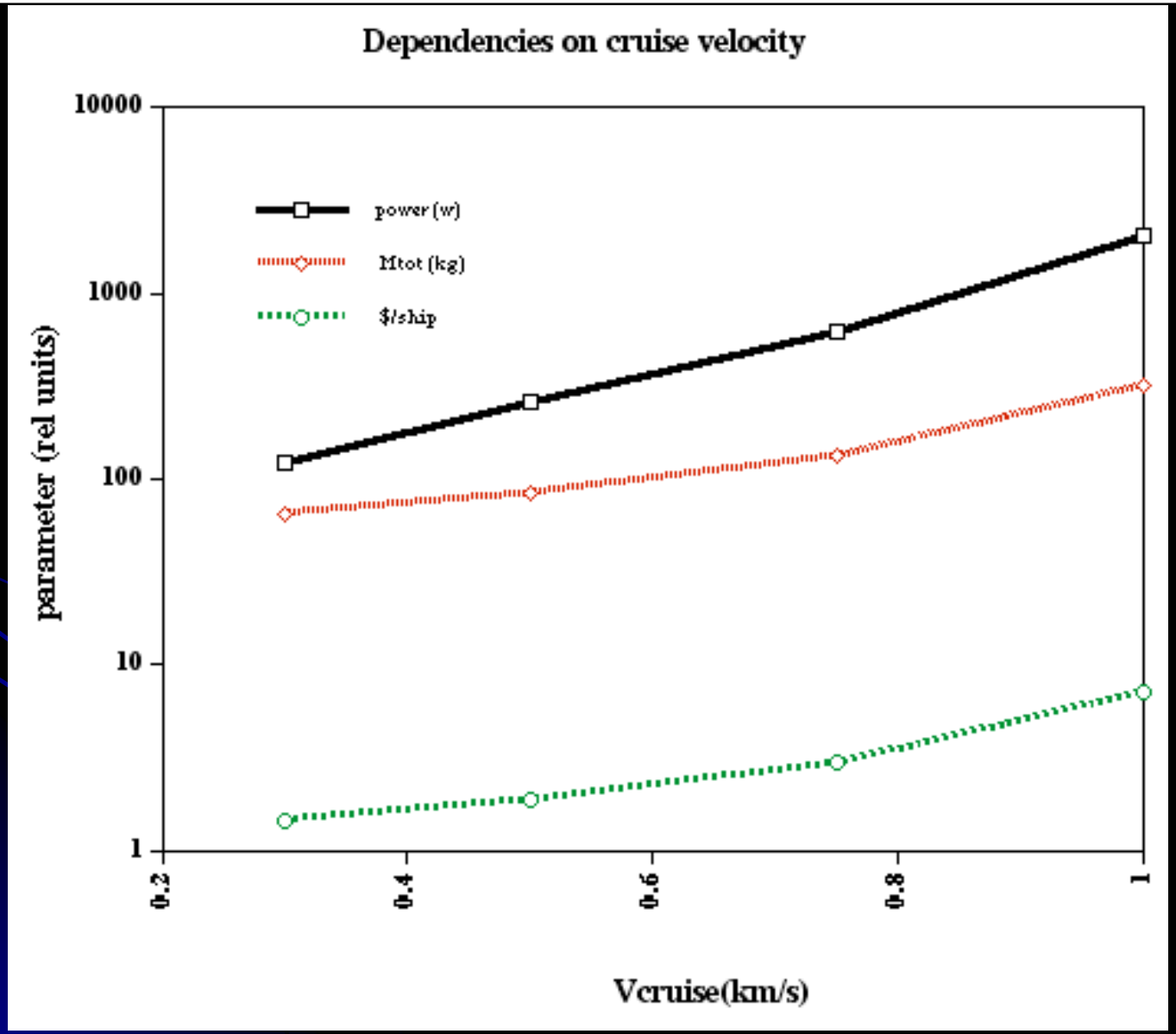
Deployment – Nuclear Thermal Rocket

- Current NASA program, Prometheus, is interested in recovering the NTR to fulfill the new Presidential space exploration direction
- NTR is considered to be a demonstrated technology that could be recovered within a decade
- Assumed operating parameters
  - 5000 lb thrust engine
  - T/W = 3
  - Isp= 950 s
  - Hohmann transfer orbit – sum of ΔVs= 9.52 km/s
  - Reusable for N missions

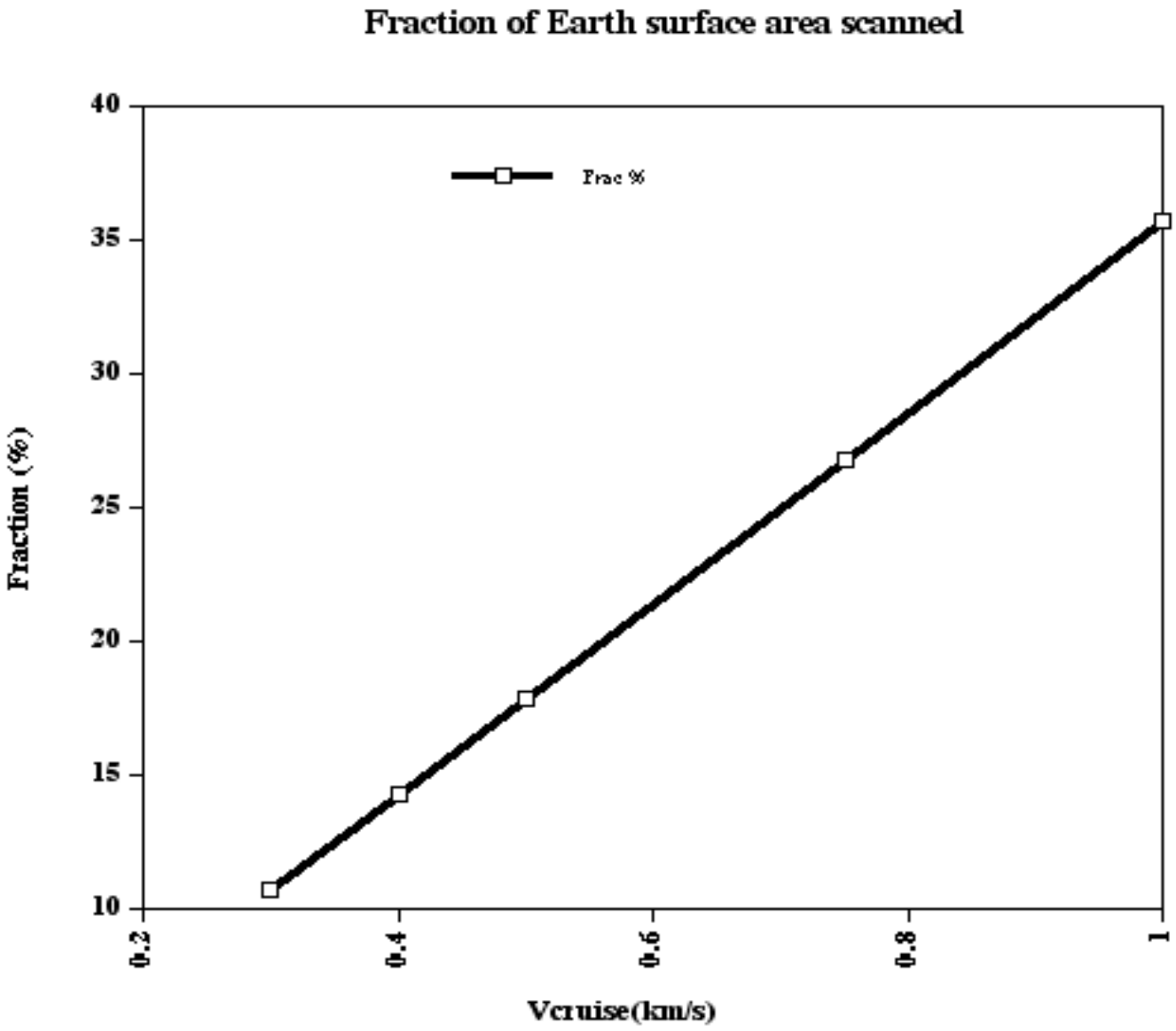
Preliminary optimization calculations are positive

- Power level is dictated by the propulsion systems need to accelerate over a short period (variable)
- The same power level is sufficient for communications back to Earth, water extraction, neutron generation, and the radar systems.
- The average cruise velocity, Isp, time of acceleration, and interception velocity are independent variables
  - Propellant requirements for initial acceleration to cruise, intercepts, and refueling are determined
  - Power system mass including waste heat radiator is found for the tuned PV method

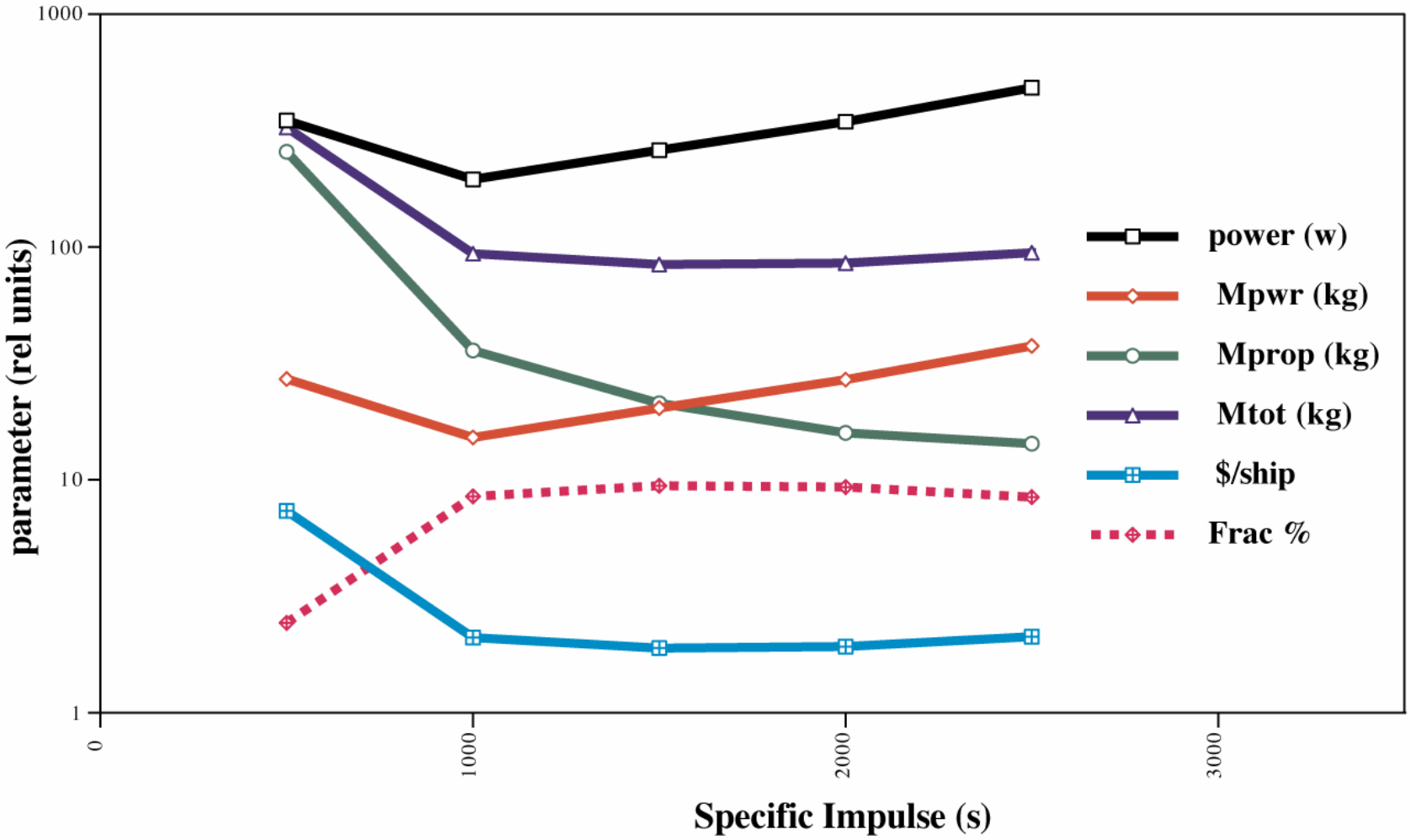
Ship characteristics depend strongly on the average cruise velocity



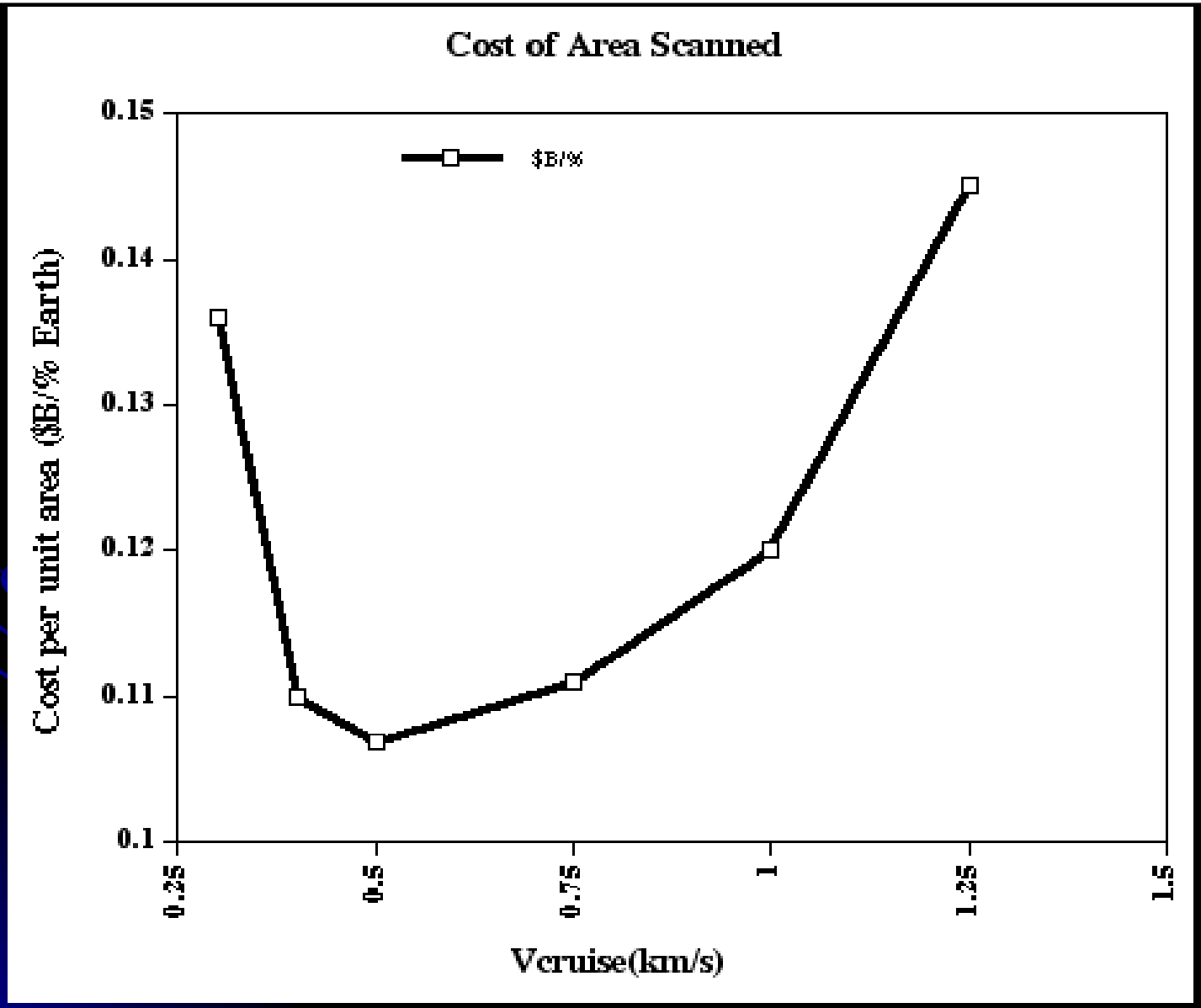
Significant surface area can be scanned by reasonable cruise velocity



Optimum specific impulse lies within achievable values



Preliminary cost optimization indicates lower than expected cruise velocity



Phase II will strive to resolve several issues

- Lifetimes-
  - Power conversion scintillator
  - RF taggers
  - Microwave generator
  - detectors
- Need time dependent simulation to develop guidance, control algorithms, and $V_{intercept}$
- Radar – mass and power
- Earth communications
- Packaging- is the platform volume limited or mass limited

Conclusions

- A host of small platforms can survey a significant fraction of the asteroid population in a 20 year interval
- The land area surveyed could be equal to a major fraction of the Earth's surface area
- The energetic radioisotope power supply appears adequate for the mission needs
- Most subsystem hardware has current-day examples that can be improved
- A time-dependent simulation is needed for flight profile demonstration and targeting algorithm development