The Near Earth Asteroids as the First Step on the Way to Mars*

Bruce L. Cutright[1]

Search and Discovery Article #80157 (2011)
Posted June 27, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

[1]Bureau of Economic Geology, University of Texas at Austin, Austin, TX (bruce.cutright@beg.utexas.edu)

Abstract

We have identified, as of July, 2010, over 7100 near earth asteroids, 810 of which are greater than one kilometer in diameter and 149 that are identified as potentially hazardous earth impactors by NASA's Near Earth Objects Program. This paper examines the advantages of exploring and exploitation of the near earth asteroids as the first component of a larger space exploration program and provides arguments for revising our focus on chemical rocket propulsion systems for effective space exploration.

The recent cancelation of NASA's Constellation program has shifted the emphasis of the US space program from returning to the moon to exploring Mars and the asteroids. The Apollo program and the Viking, Pathfinder and Mars Rover programs developed a significant body of information on the composition and characteristics of the Moon and Mars. We have progressed to the point that we can manufacture simulated Lunar and Martian regoliths for experimentation with extraction of useful materials for life support, construction materials and development of traction and weight-bearing capabilities for exploration vehicles. Although the near earth asteroids have not attracted the public attention that the Moon and Mars have, they represent the easiest accessible sources of fuels, minerals and life support materials once off the Earth's surface. Further, expanding our knowledge of the asteroids, their composition and dynamics, addresses two critical parameters: the asteroids provide fundamental information about the origin of the inner planets and solar system, and detailed information on their orbital dynamics is the only way of predicting the fate of earth crossing and potentially Earth impacting asteroids.

Missions such as the Japan Hayabusa sample return program, ESA's Rosetta program and the NASA's Deep Space-1, NEAR and Stardust programs have provided excellent information on the mineralogy, metallic and volatile content of the near-earth asteroids as well as information on the engineering properties of the asteroid bodies themselves. In addition, the collections of meteorites that have fallen to earth and subsequently analyzed extensively provide a greater volume of direct samples than what is available from the Lunar

return missions. From these analyses it is clear that the near earth asteroids represent an extremely valuable reservoir of strategic metals and volatiles that can support an expanded asteroids-Moon-Mars exploration effort.

THE NEAR EARTH OBJECTS as the First Step on the Pathway to Mars

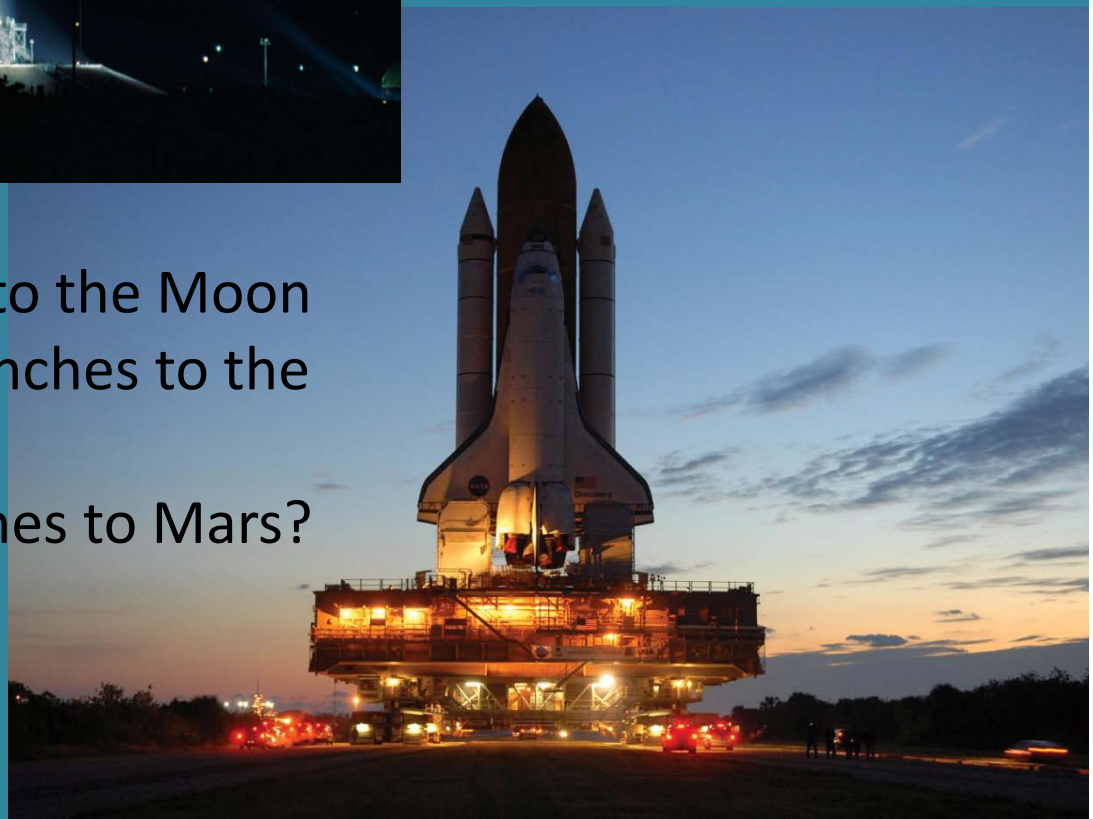
The difficulties of getting to space, from deep within the gravity well of earth, disappear once we are in space, so why would we go back?

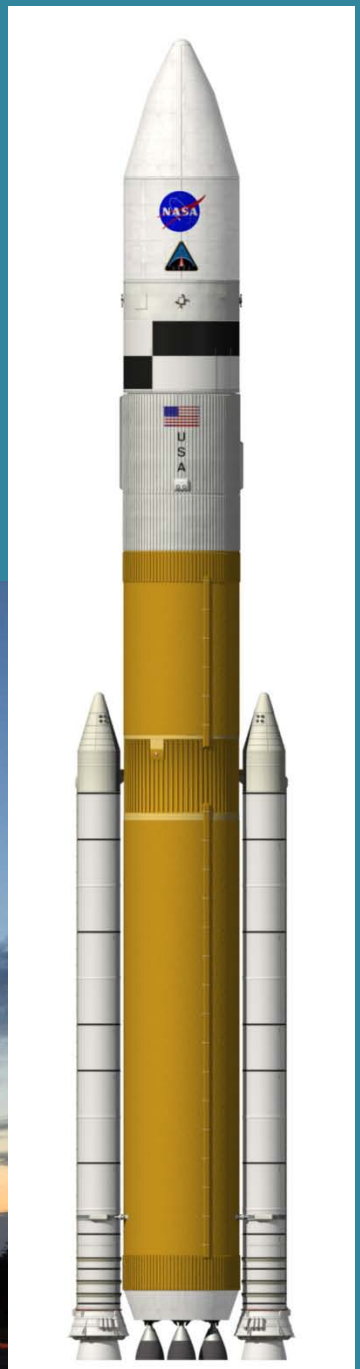
Bruce L. Cutright, Bureau of Economic Geology, John A and Katherine G Jackson School of Geosciences, The University of Texas at Austin

Apollo 15

Space Shuttle Discovery, and

ARES-V





- One Launch to the Moon
- Multiple Launches to the ISS in LEO
- 2 to 4 Launches to Mars?

- **Defining the Question;**
  - **Assumption: Space Exploration will continue, with active programs by Japan, China, India, Europe and Russia. It is in the interests of the United States to Participate and Lead in this endeavor.**

- **Q1. Focusing only on the primary question of manned missions; should the predominant effort of the US Manned Space Program be directed toward:**

  Mars

  The Moon

  Near Earth Asteroids

Hubble image of Ceres, the largest asteroid in the main asteroid belt, compared with four other asteroids and Mars.
(Longest dimension for each body in parentheses.)

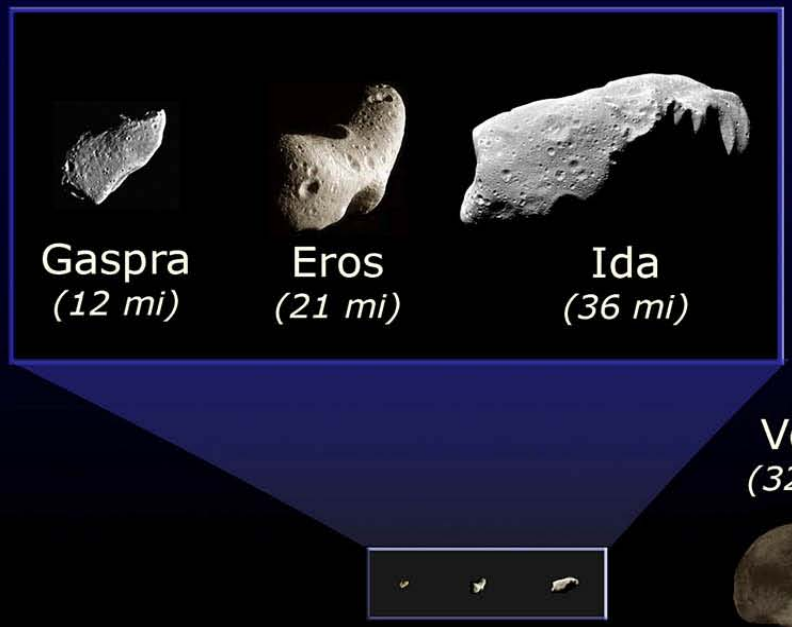


Image credits: Gaspra, Ida: Galileo (NASA/JPL); Eros: NEAR Shoemaker (JHU/APL).
Vesta and Mars images: HST (NASA/STScI).

The Moon

- **Logistics:** Physically closest, making telepresence operations easy with minimum time lag
- **Economic:** Nearby source of Helium 3, ideal isotope for fusion energy production.
  - $^{3}He + {}^{6}Li \rightarrow 2\ {}^{4}He + p + 16.9\ MeV$
  - $D + {}^{3}He \rightarrow {}^{4}He + p + 18.3\ MeV$
  - $^{3}He + {}^{3}He \rightarrow {}^{4}He + 2p + 12.9\ MeV$

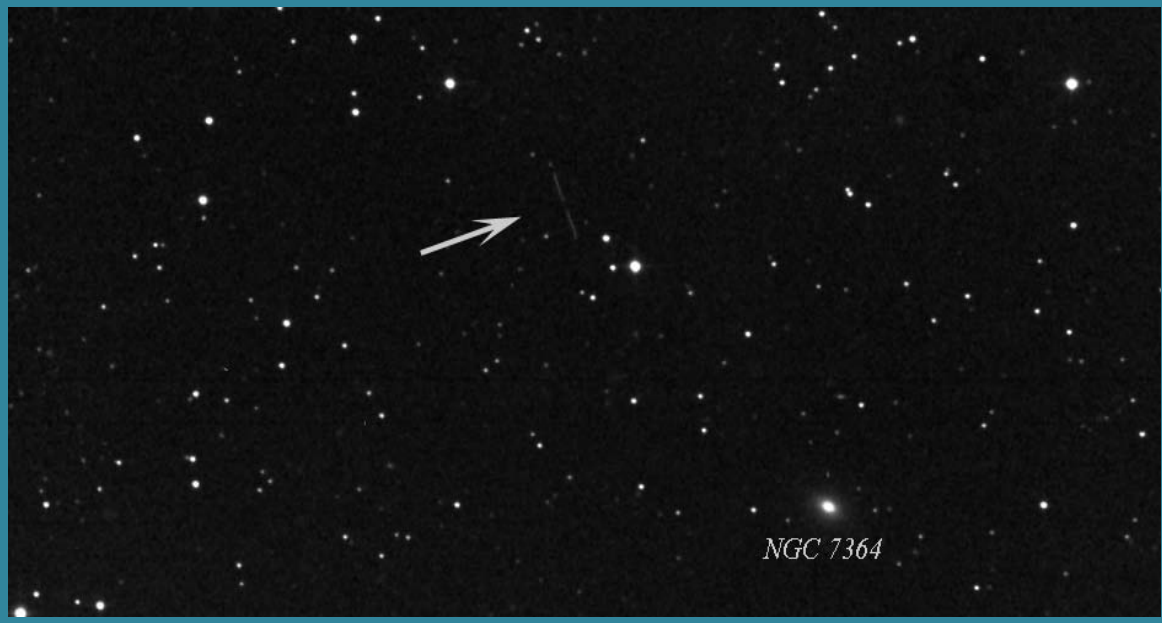
- **Science:** Radio Shadow on "dark side" of the moon
- Much left to explore

Mars

- Another World with the same land area as the Earth!
- Contains vast supplies of water and an atmosphere
- It may harbor life, or evidence of past life
- In Situ Resource Utilization is possible for nearly all necessary materials for colonization, with the possible exception of organics (Phobos and Deimos might be nearby source of organics, as they resemble Carbonaceous Chondrites)

Near Earth Objects:

Generally between the orbits of Venus and Mars, with Apollo (60%) and Aten (6-8%) Asteroids crossing Earth's orbit and Amor (30%) Asteroids outside Earth's orbit and may cross Mars' orbit. Inner Earth Objects are within Earth's orbit and may cross Venus' orbit. Dormant Comets may comprise 1-6 % of total number.



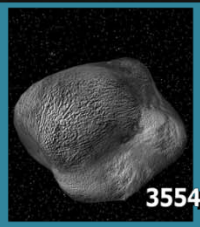
C-Type

75% of known asteroids
CI and CM chondrites:
volatiles: 5-20% water

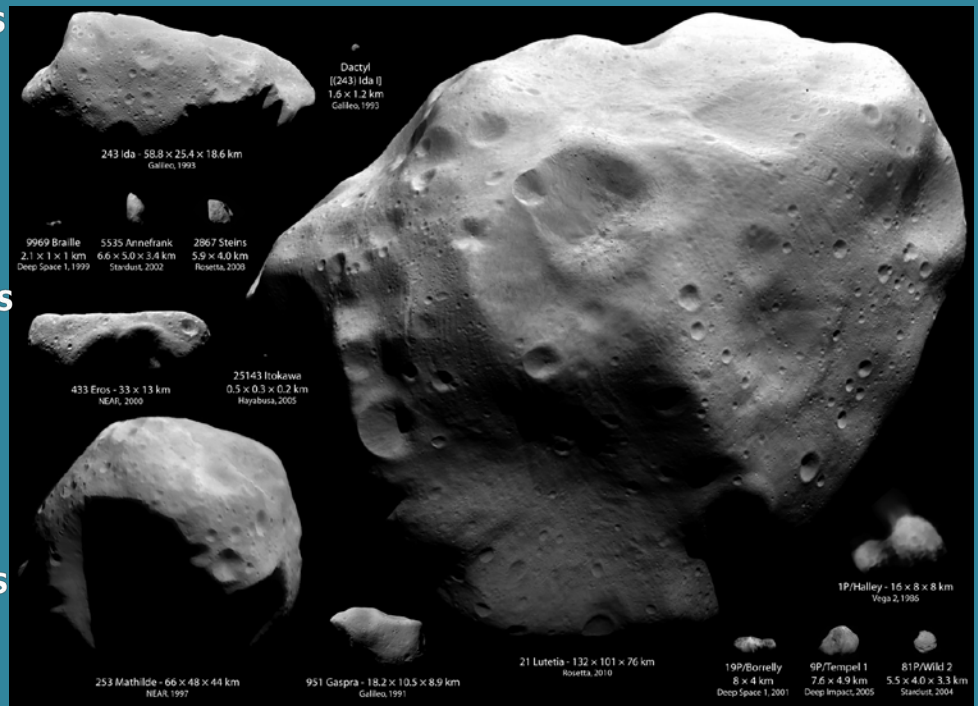
S-Type

15% of known asteroids
dominant in inner belt:
olivine, pyroxene, Fe

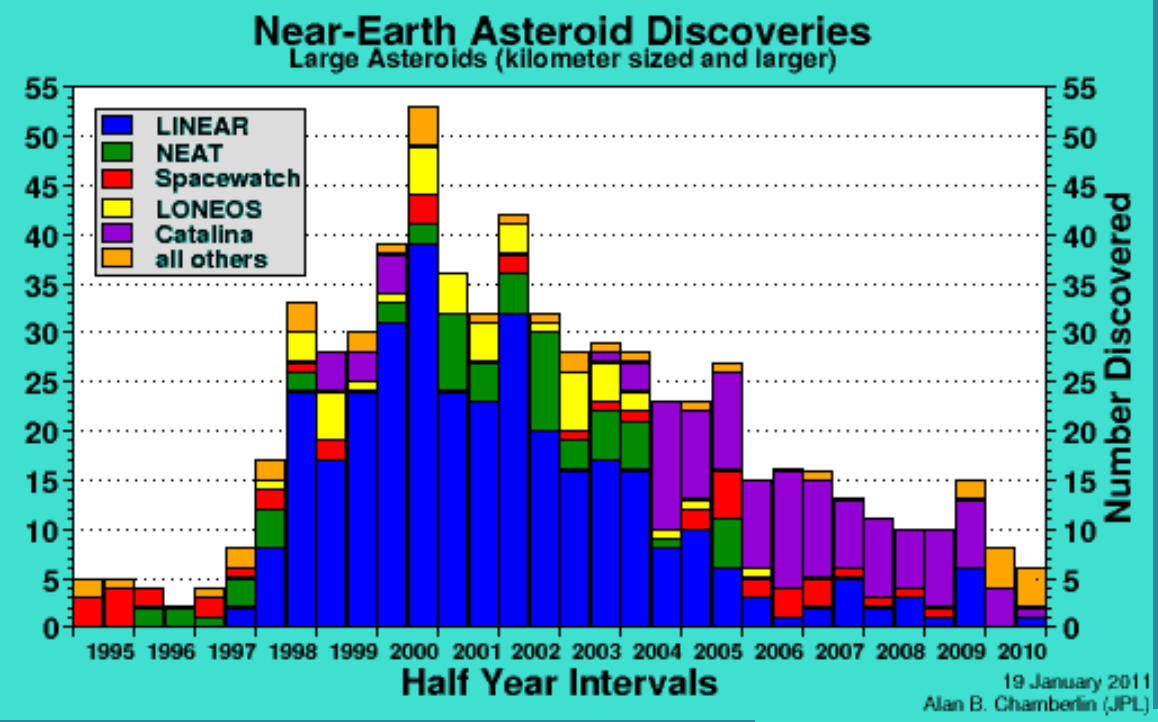
M-Type



10% of known asteroids
Fe, Ni, Co, Pt-group

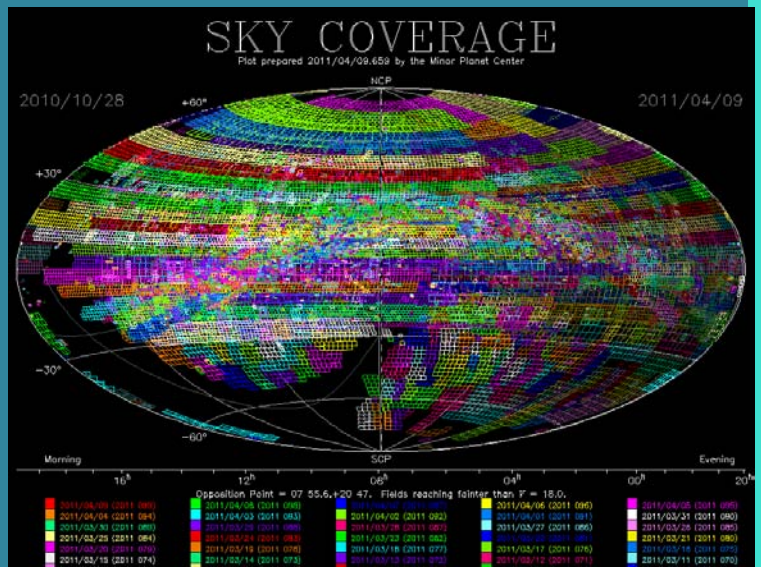


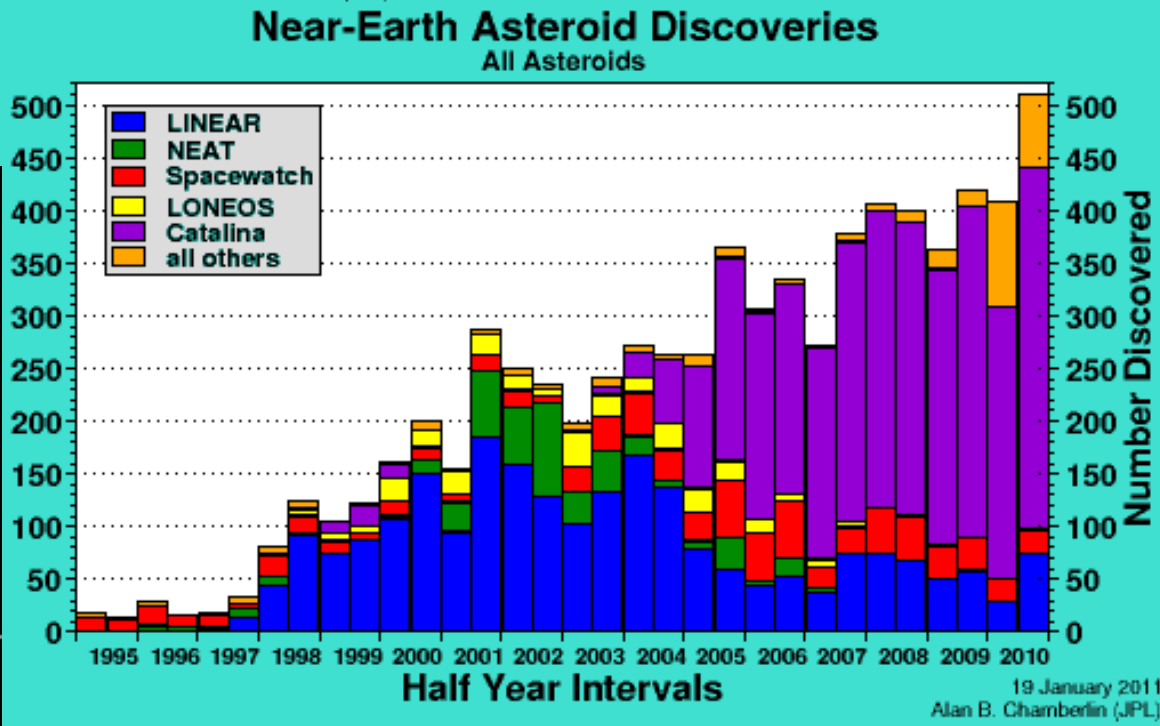
- Why are we interested in the Near Earth Asteroids and Comets?
  - **Logistical Issues.** The Near Earth Asteroids represent the easiest local sources of in-space rocket fuels, volatiles and oxygen to support extraterrestrial space missions
  - **Economic.** The NEAs contain essentially an unlimited supply of strategic materials, platinum group metals and cobalt, nickel and iron for building materials.
  - **Science.** The asteroids and comets provide unique windows on the characteristics of the early solar system, and a platform for monitoring near sun conditions, and outer planet environments.
  - **Self Preservation.** Earth crossing asteroids and comets greater than 50 meters in diameter represent potentially catastrophic events that threaten Earth's environment. Detection, monitoring and intervention can only occur if we are aware of the impending impact.

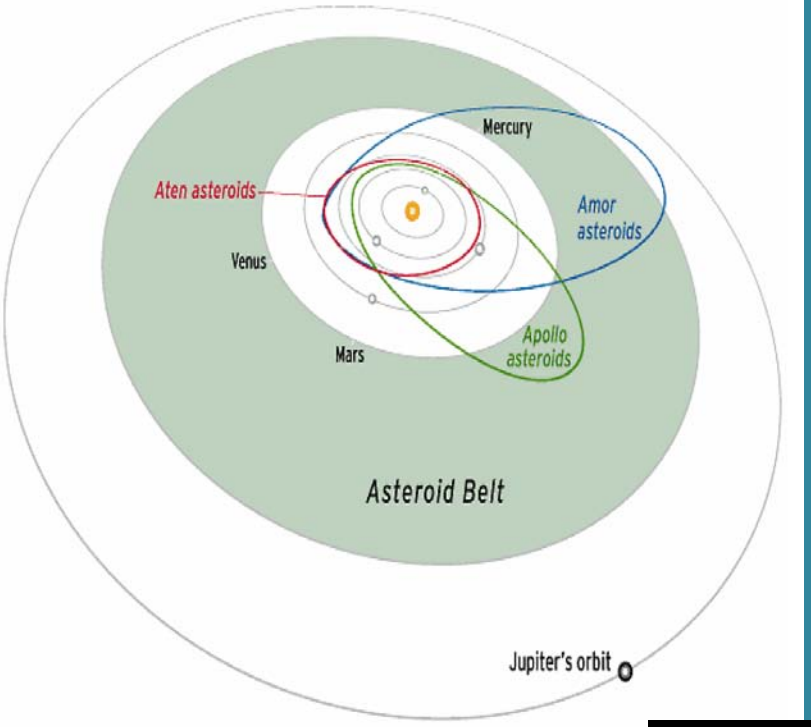


NEO Discovery Statistics
as of January 19th, 2011

- 87 Comets
- 7,970 total number discovered
- 824 Larger than 1 KM
- 1,217 with orbits that pass within 0.05 AUs of Earth (PHA)
- 148 PHAs larger than 1 km





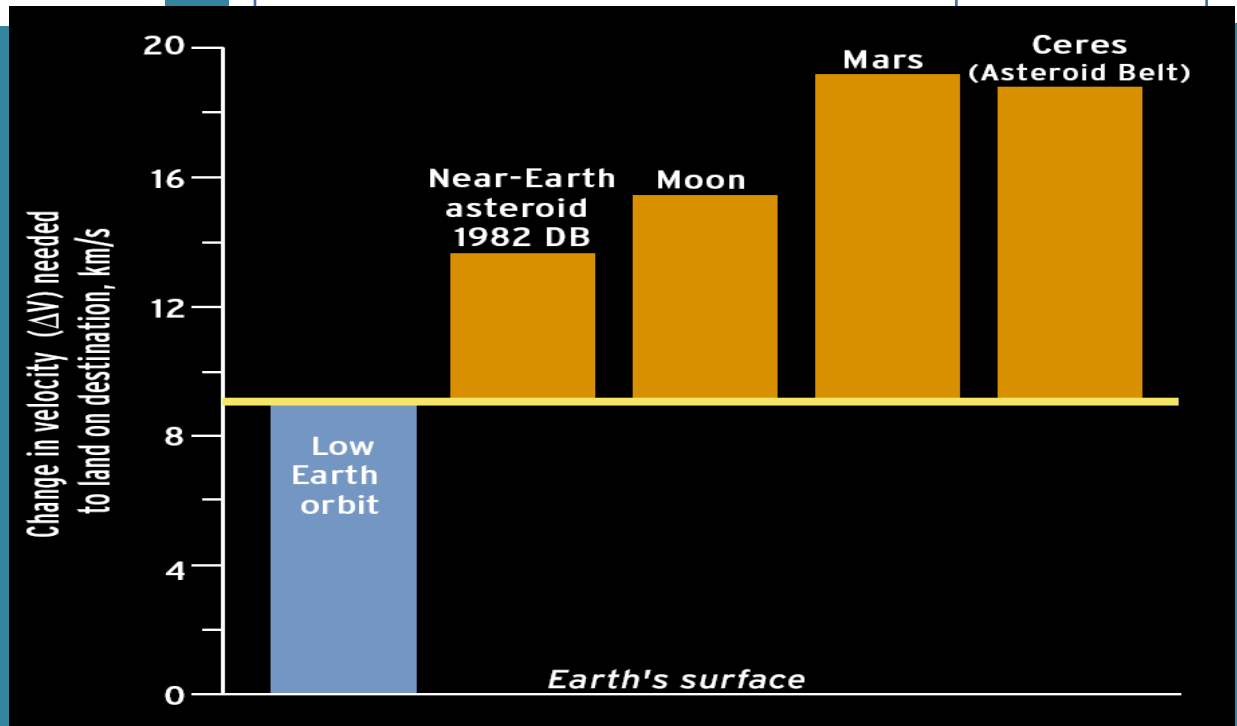


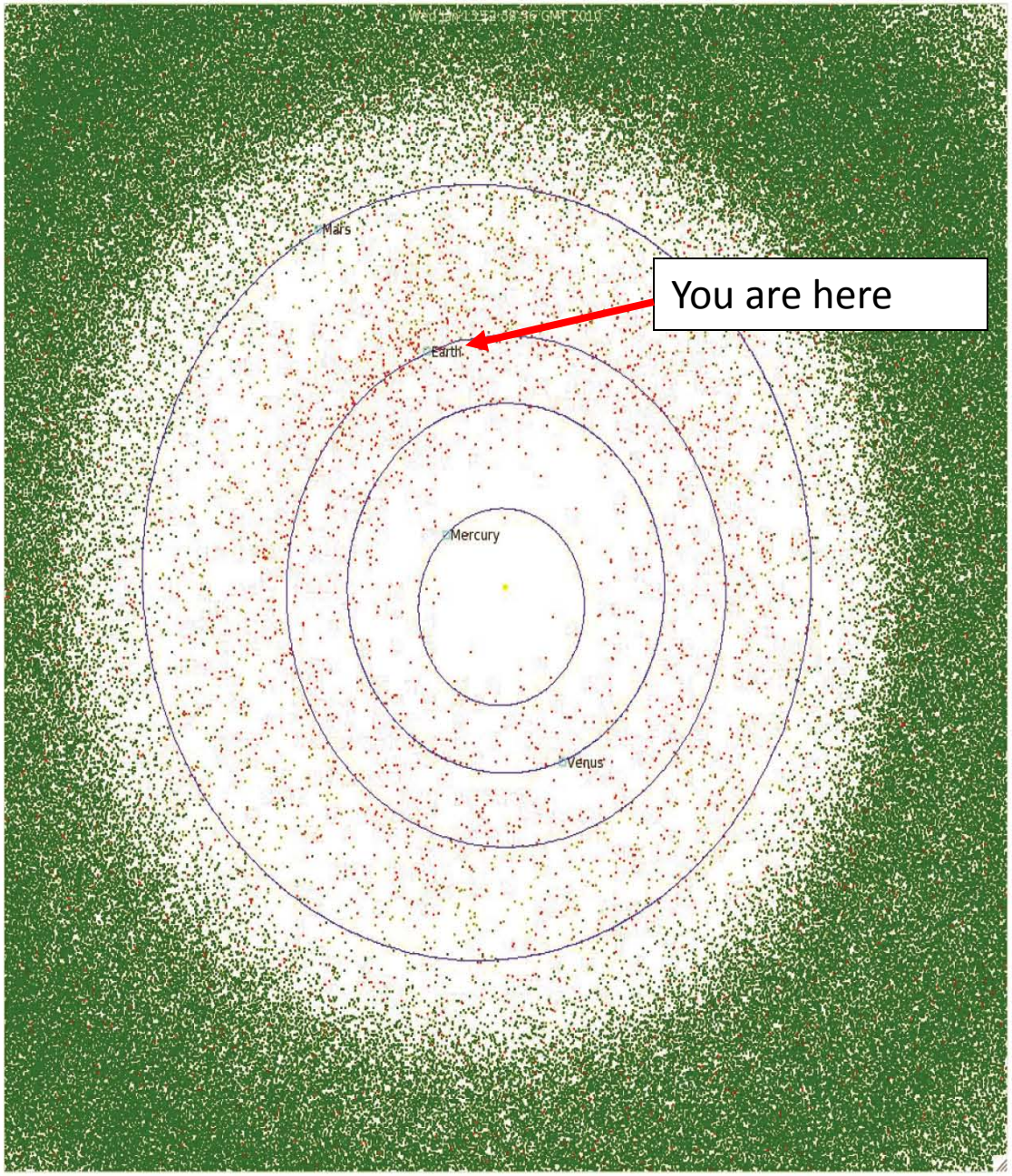
Mission Energy Requirements (Δ-v)

Transfer	Delta-V (km/s)
Earth surface to low-Earth orbit (LEO)	8.5
Earth surface to escape velocity	11.2
Earth surface to geosynchronous orbit (GEO)	11.8
LEO to escape velocity	3.2
LEO to Mars transfer orbit	3.7
LEO to GEO	3.5
LEO to highly-elliptical Earth orbit (HEEO)	2.5
LEO to Moon landing	6.3
LEO to near-Earth asteroid[a]	4.0
Lunar surface to LEO (aerobraking)	2.4
Near-Earth object (NEO) to Earth transfer orbit	1.0
Phobos/Deimos to LEO	8.0

Logistics: Easily accessible, in most cases, easier than getting to the Moon, and always easier than returning from the Moon or Mars.

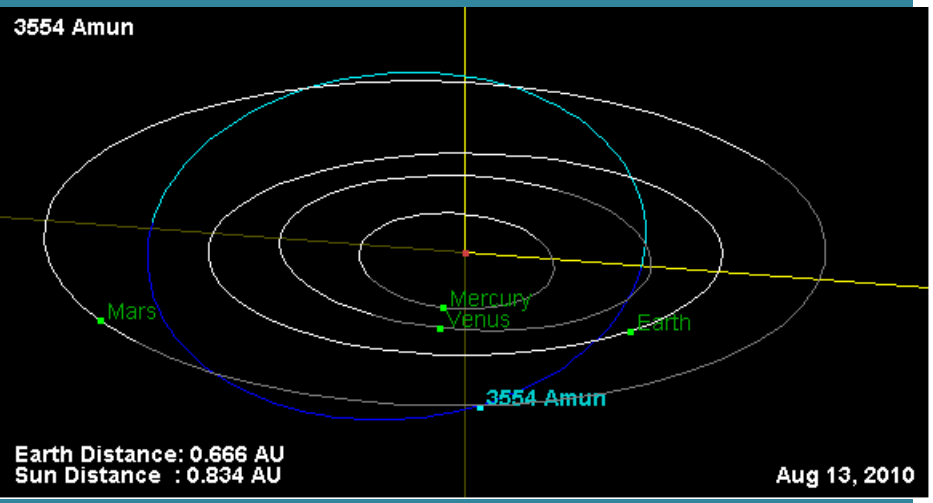
Source: Ingebretsen, 2001





Source:
Defending Planet Earth.
National Academies Press 2010

FIGURE 2.3 The distribution of currently known asteroids (in January 2010). The green dots represent asteroids that do not currently approach Earth. The yellow dots are Earth-approaching asteroids, ones having orbits that come close to Earth but that do not cross Earth's orbit. The red boxes mark the locations of asteroids that cross Earth's orbit, although they may not necessarily closely approach Earth. Contrary to the impression given by this illustration, the space represented by this figure is predominantly empty. SOURCE: Courtesy of Scott Manley, Armagh Observatory.



Note that 0.66 AU is less than 100 million kilometers away

Mineralogical, Chemical and Physical Properties of Asteroids

	Mineral	C2-Type	C1-Type	S-Type	M-Type	Lunar Regolith
Free Metals	Fe	10.7%	0.1%	6-19%	88%	0.1%
	Ni	1.4%	—	1-2%	10%	—
	Co	0.11%	—	0.1%	0.5%	—
Volatiles	C	1.4%	1.9-3.0%	3%	—	0.014%
	H2O	5.7%	12%	0.15%	—	0.045%6
	S	1.3%	2%	1.5%	—	0.12%
Mineral Oxides	FeO	15.4%	22%	10%	—	15.8%
	SiO2	33.8%	28%	38%	—	42.5%
	MgO	23.8%	20%	24%	—	8.2%
	Al2O3	2.4%	2.1%	2.1%	—	13.8%
	Na2O	0.55%	0.3%	0.9%	—	0.44%
	K2O	0.04%	0.04%	0.1%	—	0.15%
	P2O5	0.28%	0.23%	0.28%	—	0.12%
	CaO	—	—	—	—	12.1%
	TiO2	—	—	—	—	7.7%
Physical	Density (g/cm^3)	3.3	2.0-2.8	3.5-3.8	7.0-7.8	1.5-1.9

Asteroid 3554 Amun (1986)	*Mass*	*Diameter*	*Classification*
(discovered by C. Shoemaker)	1 x 10^{13} kg	2.48 Km	Aten
Platinum Group Metals			Value (2005 data)
Platinum, Ruthenium, Rhodium, Palladium, Osmium, Iridium			$6 Trillion
Iron and Nickel			$8 Trillion
Cobalt			$6 Trillion
Total			$20 Trillion
Estimated Cost to Acquire and transport to Earth			$10 to $50 Billion
Net Return			$19.99 to $19.95 Trillion

Sources: Gerlach, 2005. JPL NEO program Office. J.S. Lewis, 1996

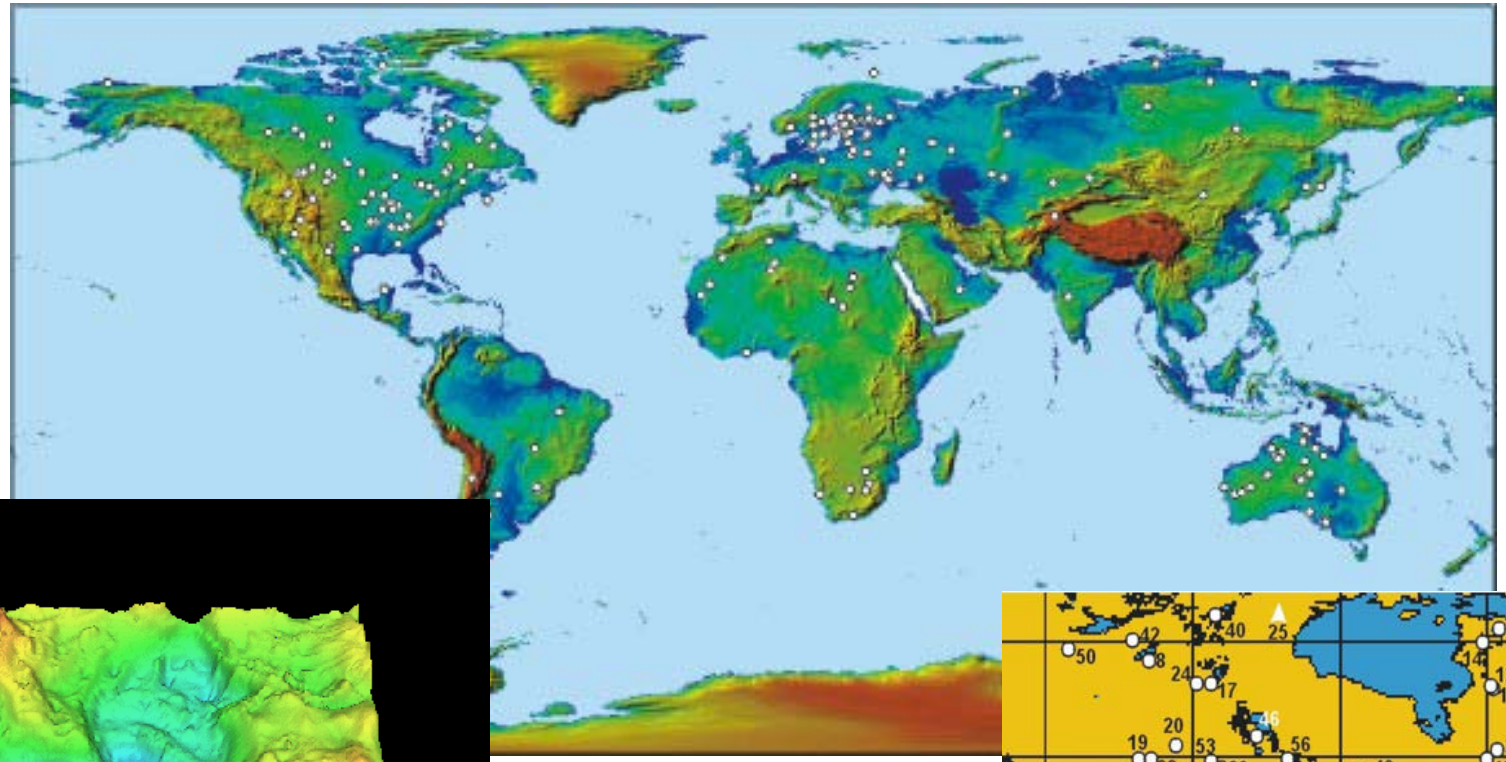
Table (Modified after Kargel, 1996)
Concentrations and Potential Value of Rare Earth Elements, Precious Metals and Platinum Group Metals in "Typical" Asteroids Derived from Chemical Composition of Meteorite Finds on Earth

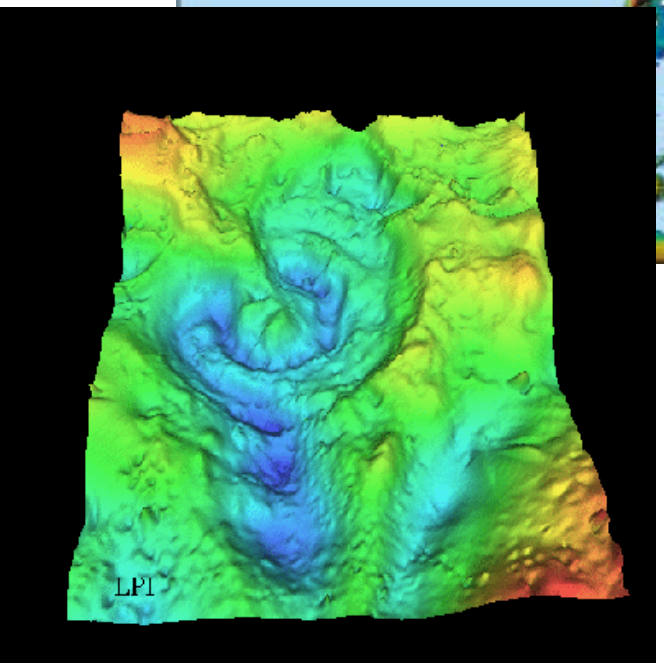
Element	Conc in Average LL-Chondrite	Conc in "Good" Iron Asteroid (90th percentile in Ir and Pt)	Conc in "Best" Iron Asteroid (98th percentile in Ir and Pt)	Mass in 1 km diameter "good" Asteroid (metric tones)	Market Value in late 2010 prices ($/kg)	Value if sold at today's market price in $	Deflated 2010 Market Value (assumed to be 10% of full 2010 value)
Semiconductors							
Phosphorous (P)		1300ppm		2.25E6	0.06	1.24E8	1.24E7
Gallium (Ga)		60 ppm		1.04E5	480.00	4.98E10	4.98E9
Germanium (Ge)	1020ppm	210ppm	0.05-35 ppm	3.63E5	950.00	3.45E11	3.45E10
Arsenic (As)		3.7 ppm		6.39E3	2.02	1.29E7	1.29E6
Selenium (Se)		36.0 ppm		6.22E4	50.60	3.15E9	3.15E8
Indium (In)		0.46 ppm		7.95E2	500.00	3.97E8	3.97E7
Antimony (Sb)		0.047 ppm		8.12E1	5.06	4.11E5	4.11E4
Tellurium (Te)		0.45 ppm		7.78E2	145.00	1.13E8	1.13E7
Platinum and Precious Metals							
Ruthenium (Ru)	22.2 ppm	13.0 ppm	45.9 ppm	2.25E4	6,515.99	1.46E11	1.46E10
Rhodium (Rh)	4.2 ppm	4.8 ppm	8.6 ppm	8.29E3	79,751.86	6.61E11	6.61E10
Palladium (Pd)	17.5 ppm	1.3 ppm	1.2 ppm	2.25E3	24,595.32	5.52E10	5.52E9
Silver (Ag)		0.46		7.95E2	954.88	7.59E8	7.59E7
Rhenium (Re)	1.1 ppm	3.7 ppm	2.4 ppm	6.39E3	3,100.00	1.98E10	1.98E9
Osmium (Os)	15.2 ppm	9.0 ppm	31.3 ppm	1.56E4	14,467.84	2.25E11	2.25E10
Iridium (Ir)	15.0 ppm	33.0 ppm	31.0 ppm	5.70E4	19,871.73	1.13E12	1.13E11
Platinum (Pt)	30.9 ppm	35.0 ppm	63.8 ppm	6.05E4	55,022.79	3.33E12	3.33E11
Gold (Au)	4.4 ppm	0.16-0.70 ppm	0.06-0.6 ppm	8.64E2	45,076.31	3.89E10	3.98E9
					TOTAL	6.2E12 (see note)	6.2E11
						$6.2 trillion	$620 billion

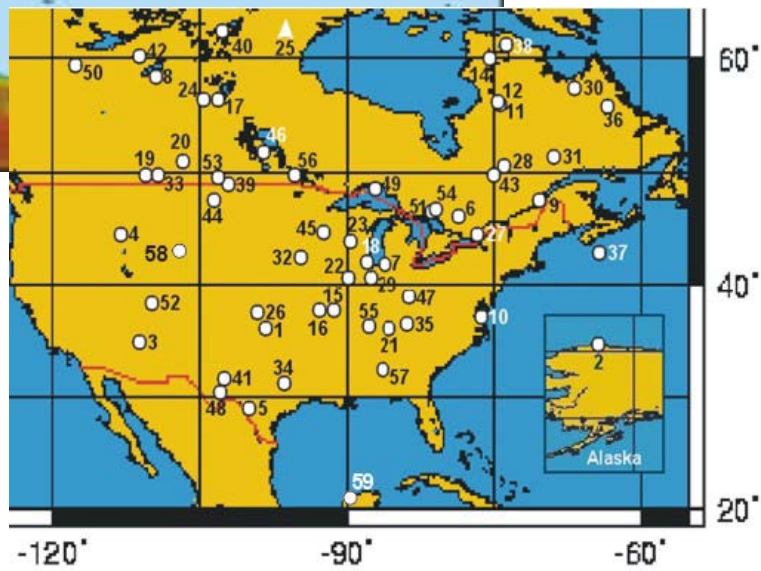
Note that 6.2E12 is shorthand scientific notation for 6.2 trillion dollars, or 6.2 x 10^{12} or $6,200,000,000,000.

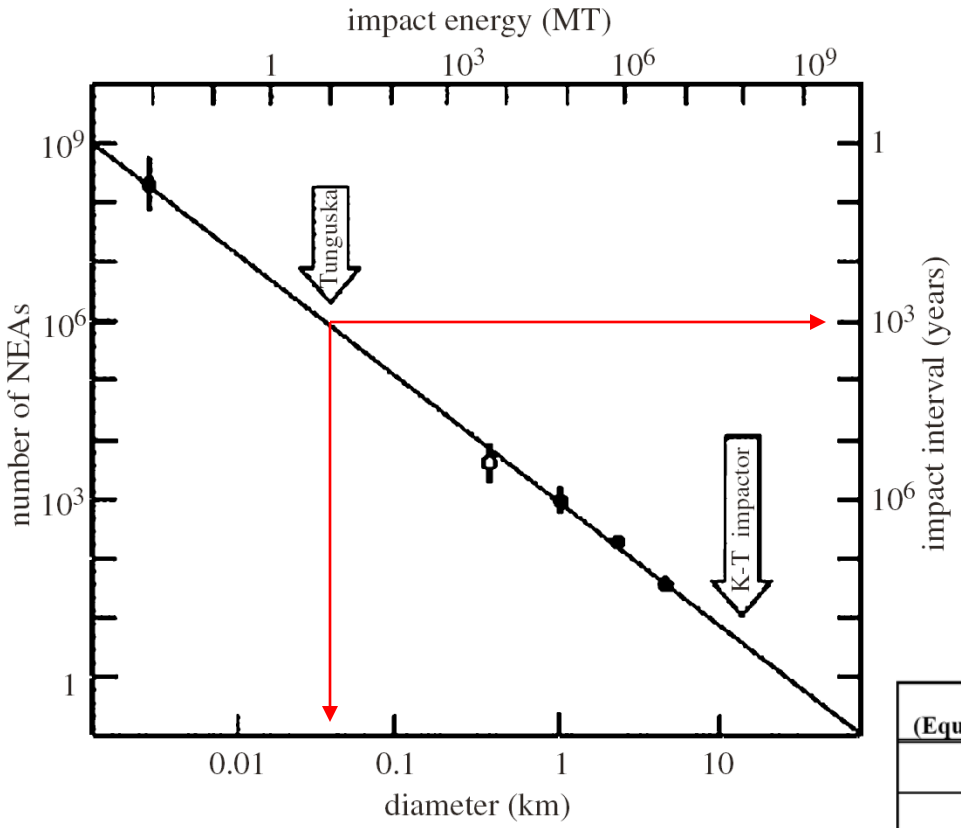
Sources: Modified after Ross, 2001; Kargel, 1996, 1994; and Jarosewich, 1990. Metal Prices from USGS Commodity Statistics and Information 2010 data and Wall Street Journal online Commodity Prices.

Location of Major Impact Structures on Earth's Surface









Source: David Morrison 2006

Table 1. Typical Kinetic Energy Released by Various Size Impactors.

Kinetic Energy (Equivalent Tons of TNT)	Asteroid Diameter	Short Period Comet Diameter	Long Period Comet Diameter
1 Megaton	89 feet *27 meters*	123 feet *38 meters*	67 feet *20 meters*
10 Megatons	192 feet *58 meters*	266 feet *81 meters*	144 feet *44 meters*
100 Megatons	413 feet *126 meters*	573 feet *175 meters*	311 feet *95 meters*
1,000 Megatons	890 feet *271 meters*	1,235 feet *376 meters*	670 feet *204 meters*
10,000 Megatons	0.36 miles *585 meters*	0.50 miles *811 meters*	0.27 miles *440 meters*
30,000 Megatons	0.52 miles *843 meters*	0.73 miles *1.2 kilometers*	0.39 miles *635 meters*
100,000 Megatons	0.78 miles *1.3 kilometers*	1.1 miles *1.7 kilometers*	0.58 miles *948 meters*
1,000,000 Megatons	1.7 miles *2.7 kilometers*	2.3 miles *3.8 kilometers*	1.3 miles *2.0 kilometers*
10,000,000 Megatons	3.6 miles *5.8 kilometers*	5.0 miles *8.1 kilometers*	2.7 miles *4.4 kilometers*
100,000,000 Megatons	7.8 miles *13 kilometers*	11 miles *17 kilometers*	5.9 miles *9.5 kilometers*
300,000,000 Megatons	11 miles *18 kilometers*	16 miles *25 kilometers*	8.5 miles *14 kilometers*
1,000,000,000 Megatons	17 miles *27 kilometers*	23 miles *38 kilometers*	13 miles *20 kilometers*

Source: James A. Marusek

Tungusta Impact Area 2,000 KM^2.

Estimated 30 to 50 meter diameter object

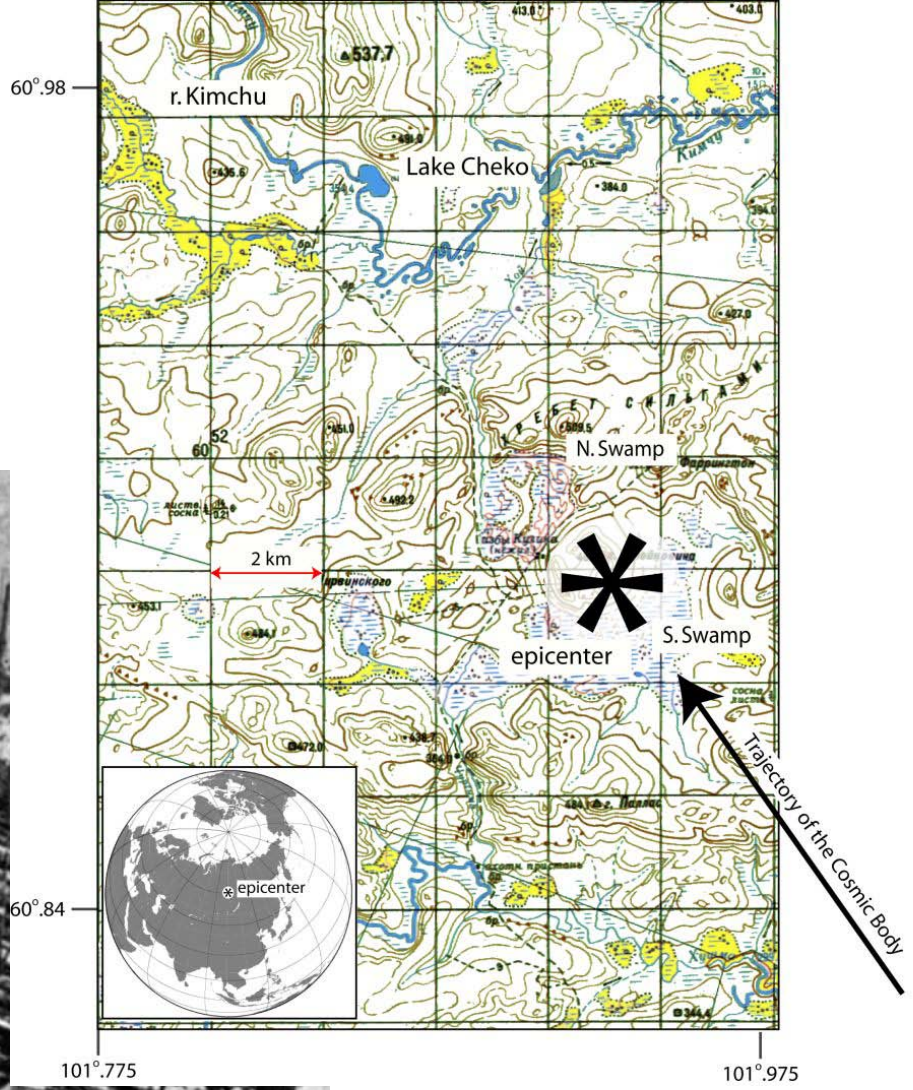
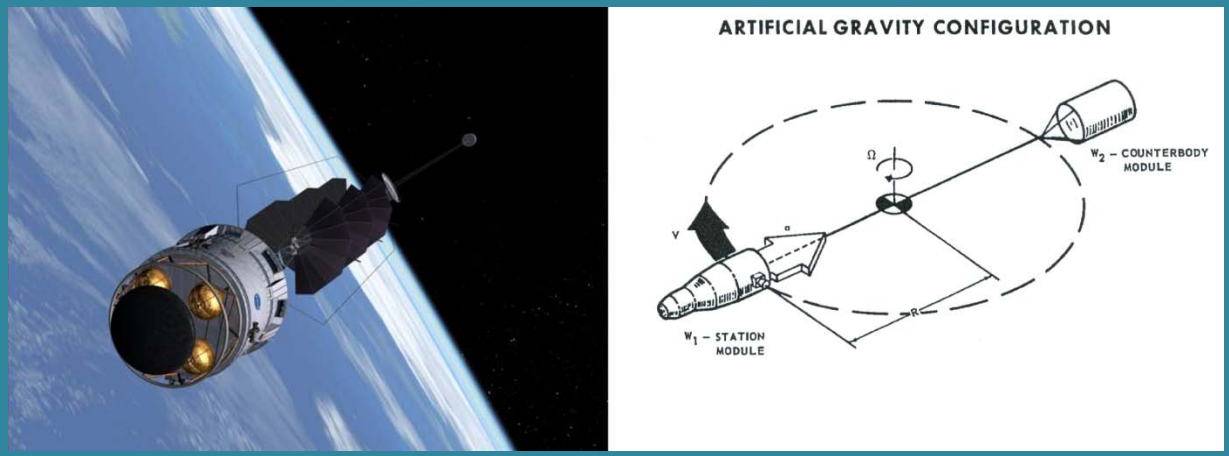


FIGURE 2.1 Meteor Crater (also known as Barringer Crater) in Arizona, with the Great Pyramids of Giza and the Sphinx inserted for size comparison. One of the most familiar impact features on the planet, this crater is about 1,200 meters in diameter and 170 meters deep; the interior of the crater contains about 220 meters of rubble overlying bedrock. The crater was formed about 50,000 years ago through the impact of an approximately 40-meter iron-nickel meteorite moving at about 13 kilometers per second (Melosh and Collins, 2005). SOURCE: Crater image courtesy of U.S. Geological Survey; composite created by Tim Warchocki.

Arguments for Near Earth Objects

1. Dormant Comets and C-Type Asteroids: High content of Water Ice and Ices of other gases and liquids.
    1. Capable of being moved to orbits around Earth, Moon or Mars, Lagrange Points
    2. Sources of Water for fuel, through disassociation to Liquid Oxygen and Liquid Hydrogen, LOX and LH2, or use of the water as fuel in nuclear thermal rocket engines.
    3. Sources of Breathing Oxygen through the same disassociation process
    4. Source of ice, or water for use in radiation shielding for orbital environments or interplanetary missions
    5. Source of Mass for use in Tethered Gravity generation.

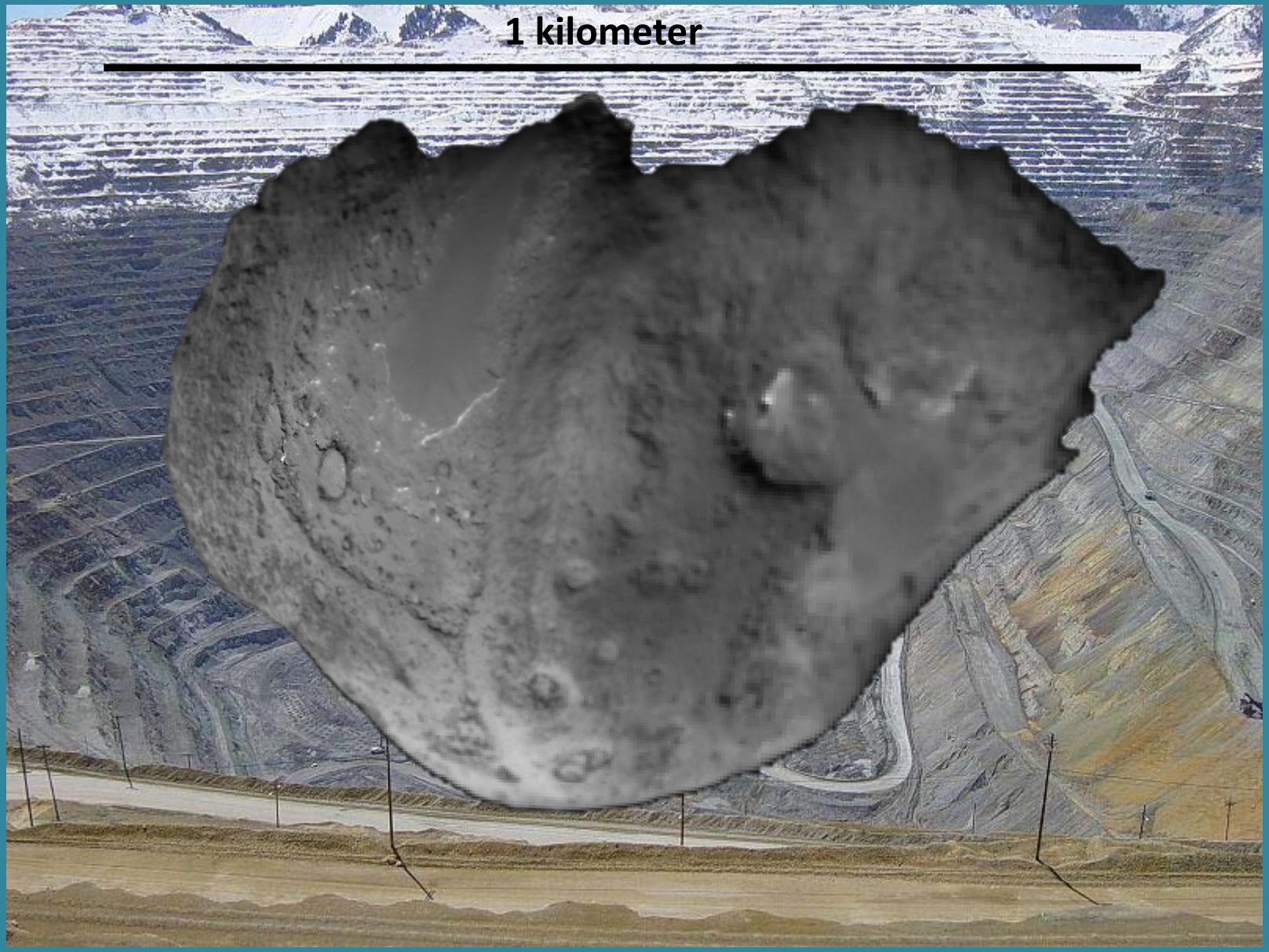


Arguments for Near Earth Objects: Economics

- Mass in orbit is worth 10 to 15 times equivalent Mass on the ground.

- If launch cost is $15,000 per Kilogram, then every kilogram in orbit is as valuable as 17 kilograms of Silver, a kilogram of Osmium or Iridium, 1/3 a kilogram of Gold or 1/5 a kilogram of Platinum.

- Conversely, a metric ton of water in space has a value of $15 Million Dollars. …….A one kilometer diameter C-type asteroid or dormant comet composed of 30 percent water, contains 150 million metric tons of water. If this had to be launched from Earth's surface it would cost 2,250 trillion dollars. We can retrieve this amount of water for less than $150 billion, as well as $6 trillion of Platinum.

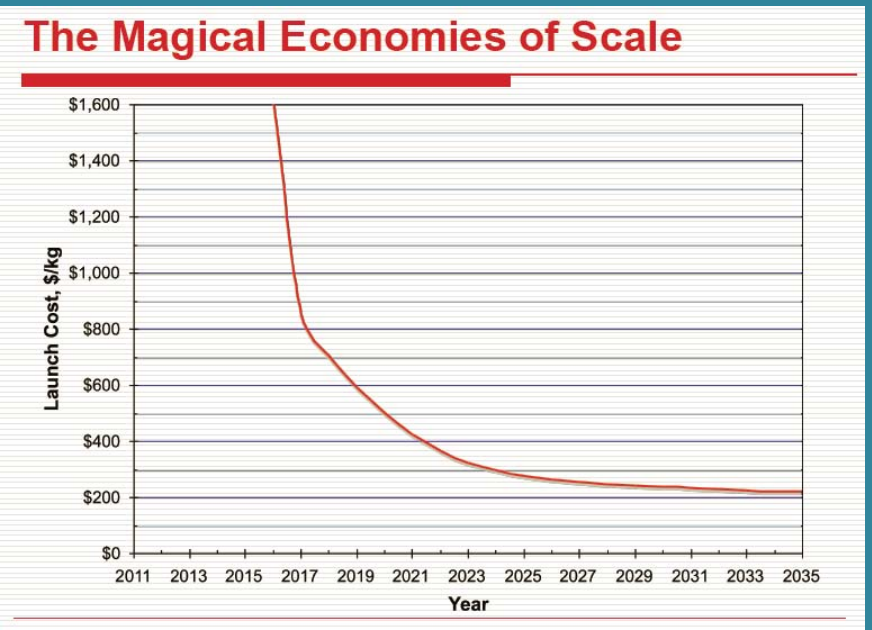


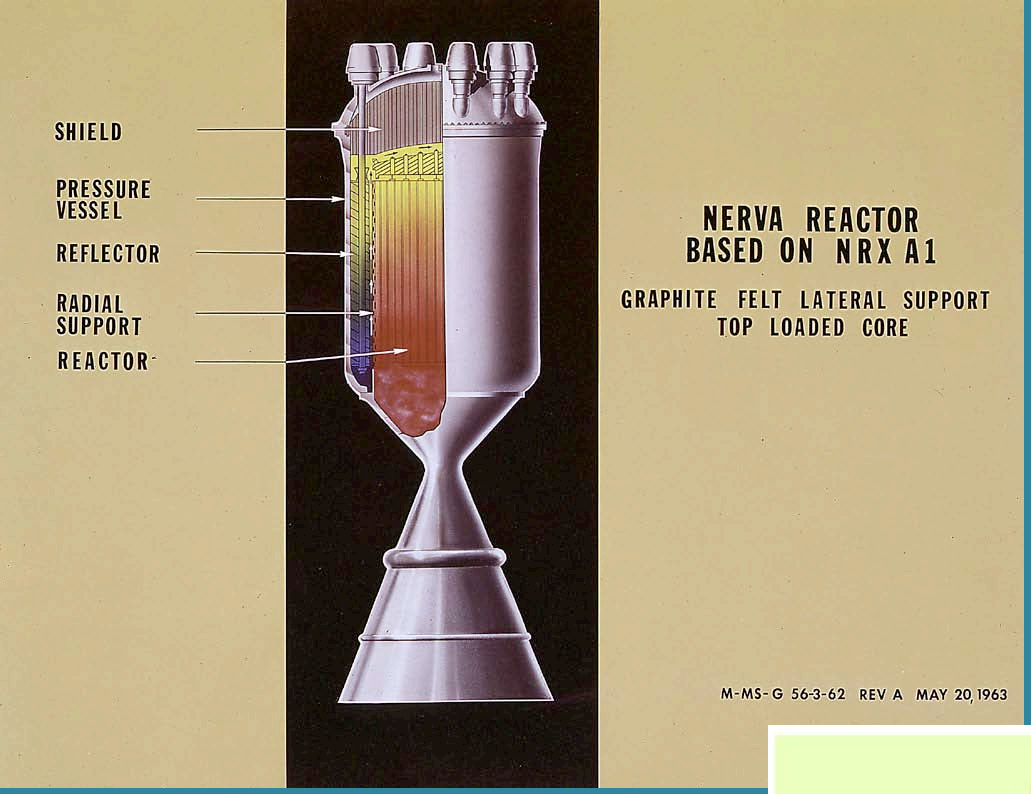
Bingham Mine, Utah for scale, with 1 kilometer asteroid in inner 1/3 of open pit mine

When we think about mining the asteroids we need to remember what we are capable of and the works that we have done before. As Arthur C. Clark stated in 1969, “the only thing that prevents the future from arriving is a failure of nerve on our part to imagine what the future can be”.
We are completely capable of great achievements, and of conquering worlds.

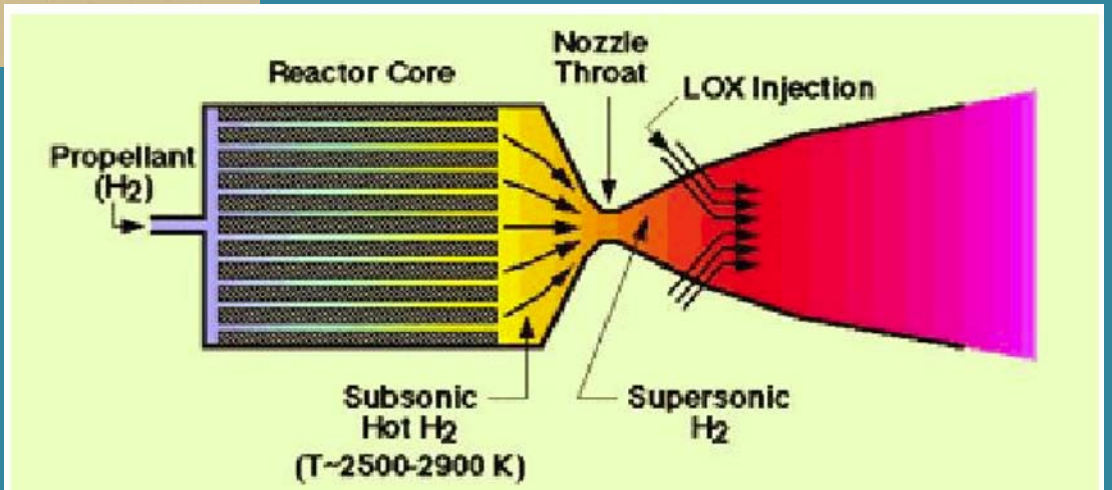
How do we achieve mining or retrieving an Asteroid or dormant comet?

- As with all of our Spaced-Based endeavors, <u>we must reduce launch costs.</u>
- We already have the technology: NERVA, LA-NTR and VASIMR





LANTR modified NERVA engine.



Operating Mode	O/F	I_{sp} (s)	Thrust (kN)	P_{jet} (MW_j)
Pure H_2 NTR	0	940	67	308
LOX-Augmented NTR	3	647	184	582

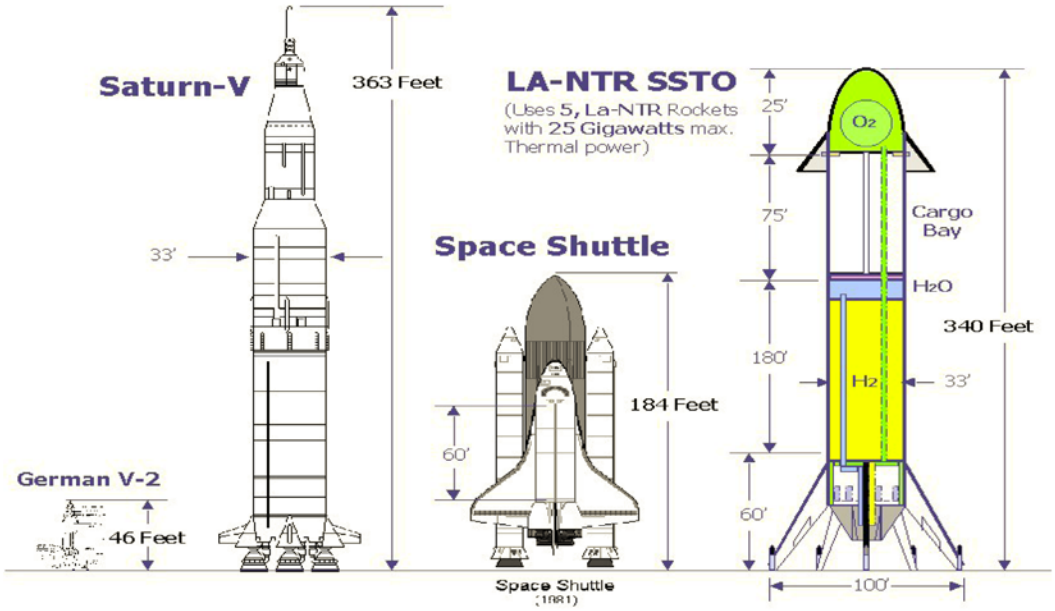


Figure 24. Nuclear DC-X/LANTR SSTO Heavy Cargo Lifter (March, 2001)

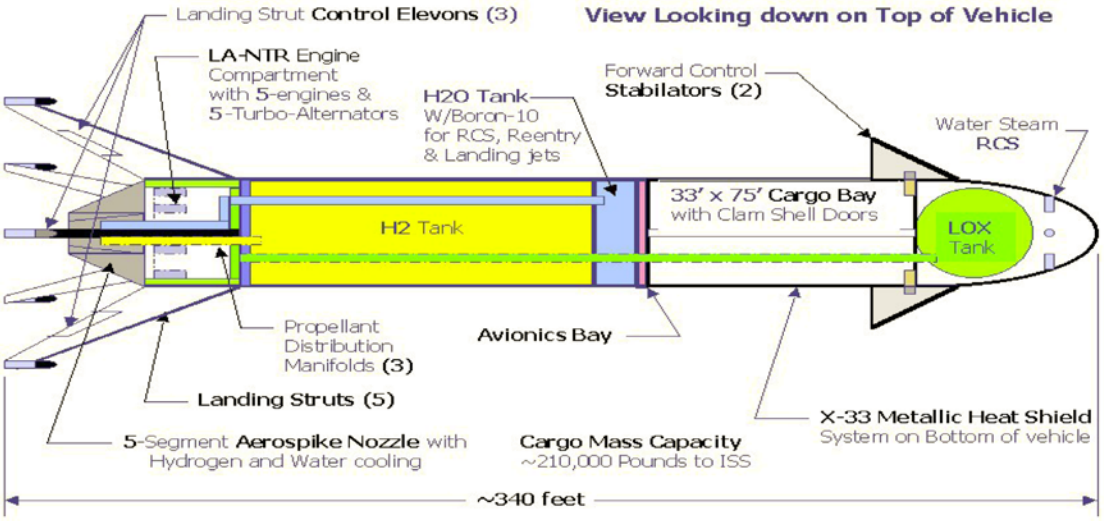


Figure 25. Nuclear DC-X/LANTR SSTO Heavy Cargo Lifter (March, 2001)

Liquid Oxygen Augmented Nuclear Thermal Rocket

Single Stage to Orbit with Vertical or Horizontal Landing capability

Launch costs estimated at $150/KG, in 2005 dollars.

"…NASA's recent space nuclear power and propulsion program initiative will hopefully re-energize nuclear propulsion R&D in a very serious way. Nuclear DC-X has such far-reaching capabilities that it represents a new and vital way of realizing the benefits of space. This advanced propulsion concept can be implemented within 5 years [from 2004] to meet all manned and unmanned space mission requirements."

Advanced Propulsion Study
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
EDWARDS AIR FORCE BASE CA 93524-7048

September 2004

Special Report AFRL-PR-ED-TR-2004-0024

We can only conclude that space exploration, and space exploitation provides incredible opportunities for the human race. But what is more important is that, whether or not we chose to enter space, space will come to us.