Investigation Opportunities

for an asteroid retrieval mission

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If we had an Asteroid Here:

What could we do with it?

The NEA Target:
Where should we put it?

We must store it in a safe place (lower Earth impact probability than a “wild” asteroid)

We must have reasonable access to it for both unmanned and manned missions

(Delta V outbound from LEO < 4 km/s)

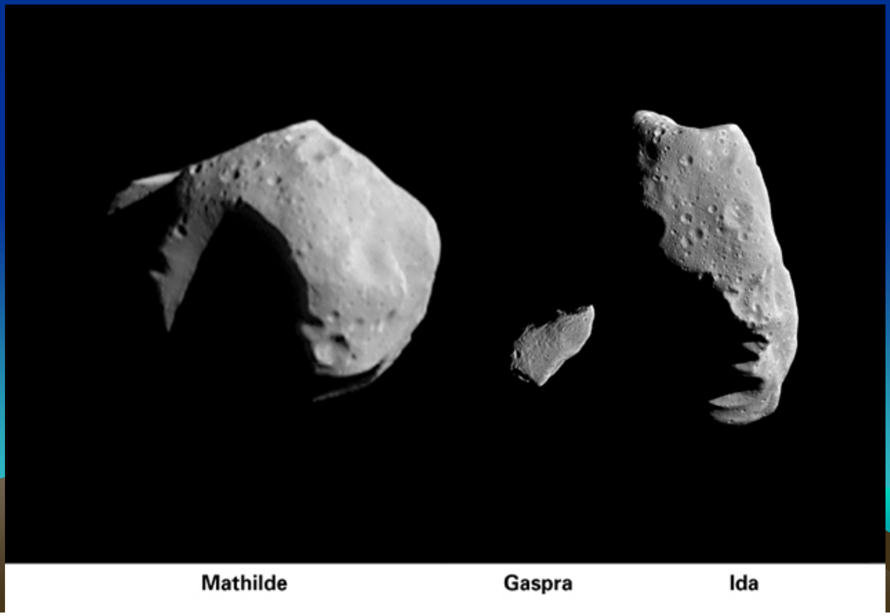
Implies lunar-anchored orbit (LLO or E/M L1)

Favored NEA Compositions

- Greatest compositional diversity in carbonaceous meteorite material
- Remote sensing UV/vis/near IR
  - Many NEA spectral classes; some match carbonaceous meteorites
- Asteroid spectral classes B, C, D, G, P, W? etc. look carbonaceous: 3 micron water absorption feature

Physical Traits of Economically Desirable Carbonaceous NEAs

- Very low crushing strength (1 to 10 bar vs. 200 to 2000 b for most stones)
- High porosity and small grain size
- Extensive regolith NOT required



Chemical Traits of C Asteroids

- Composition rich in volatiles: H, C, N, S, O, Cl, etc.
- Water carried as ice, phyllosilicates (clay), hydrated salts (gypsum, epsomite, etc.)
- Up to 6% organic polymers (analogous to tar sands)
- Additional water release by autoreduction of Fe oxides by organics: Fe_3O_4 + "CH_2" to make water vapor and carbon oxides

Research Areas: Physics

- Surface operations on an asteroid surface: dust environment
- Regolith production and coverage
- Fragmentation history via CR exposure profiles
- Internal structure (for planetary defense)
- Anchoring physics (resource and defense uses; despinning options)
- Magnetic field mapping as a tracer of T-Tauri solar wind interaction

Abundance of Useful Materials 1

- What are the most useful materials?
  - Water (ice, -OH silicates, hydrated salts) for
    - Propellants
    - Life support
  - Native ferrous metals (Fe, Ni) for structures
  - Bulk regolith for radiation shielding
  - Platinum-group metals (PGMs) for Earth
  - Semiconductor nonmetals (Si, Ga, Ge, As,…) for Earth or Solar Power Satellites

Abundance of Useful Materials 2

- Comparative abundances
  - Water
    - C, D, P chondrites have 1 to >20% H_2O; extinct NEO comet cores may be 60% water ice
    - Mature regolith SW hydrogen reaches maximum of about 100 ppm in ilmenite-rich mare basins (water equivalent 0.1% assuming perfect recovery)
  - Metals
    - To 99% in M asteroids; 5-30% in chondrites
    - Lunar regolith contains 0.1 to 0.5 % asteroidal metals

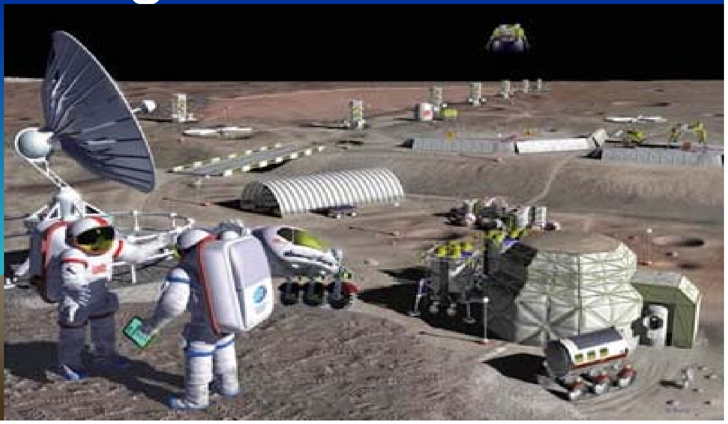
Simple, Efficient Processing Schemes

- "Simple and Efficient" means:
  - Low energy consumption per kg of product
  - Processes require little or no consumables
  - Few **mechanical** parts
  - Modular design for ease of repair
  - Highly autonomous operation
  - On-board AI/expert systems for process control
  - Self-diagnosis and self-repair capabilities
  - Maximal use of low-grade (solar thermal) energy
  - Regenerative heat capture wherever possible

Testing Processing Schemes

"Industrial Cosmochemistry"

- Ice extraction by melting and sublimation of native ice using solar or nuclear power
- Water extraction from –OH silicates or hydrated salts by solar or nuclear heating
- Electrolysis of water and liquefaction of H/O
- Ferrous metal volatilization, separation, purification, and deposition by the gaseous Mond process
  - $Fe^{o}(s) + 5CO \leftarrow\rightarrow Fe(CO)_5(g)$
  - $Ni^{o}(s) + 4CO \leftarrow\rightarrow Ni(CO)_4(g)$



Magnitude of NEA Resources

- Total NEA mass about 4x10^{18} g
- About 1x10^{18} g ferrous metals
- About 1x10^{18} g water
- Earth-surface market value of NEA metals
  - Fe iron $300/Mg x 10^{12} Mg = $300 T
  - Ni $28000/Mg x 7x10^{10} Mg = $2000 T
  - Co $33000/Mg x 1.5x10^{10} Mg = $500 T
  - PGMs $40/g x 5 x 10^{7} Mg = $2000 T

High-Utility Materials for Use in Space

- Structural metals for SPS, bases, etc.
  - High-purity iron from Mond process
    - 99.9999% Fe: strength and corrosion resistance of stainless steel
  - High-precision chemical vapor deposition (CVD) of Ni in molds
    - Custom CVD of Fe/Ni alloys
- Bulk radiation shielding
  - Regolith, metals, water (best)

Sites of Demand for NEA Materials

- LEO
  - Propellants for GTO/GEO/HEEO/Moon/Mars
  - Radiation shielding
- LLO or E/M L1-- Sites for near-moon refueling
- GEO
  - Structural metals for Solar Power Satellites
  - Station-keeping propellants
  - Photovoltaics for SPS

Propellants from Water

- Direct use of water as propellant
  - Solar Thermal Propulsion-- STP ("Steam rocket")
  - Nuclear Thermal Propulsion– NTP (")
- Electrolysis of water to H/O
  - H_2 STP
  - H_2 NTP
  - H_2/O_2 chemical propulsion →

NEAs as Travel Plazas

Many advantages to knowing how to process NEAs:

- Typical NEAs have perihelia near Earth and aphelia in the heart of the asteroid belt
- NEA regolith provides radiation shielding
- Asteroid materials provide propellants
- Earth-Mars transfer orbits possible
- Traveling hotels/gas stations/factories…

The Martian Connection

- Use NEAs as travel plazas to get to Mars
- Manned Mars mission rehearsals-- Full Mars-mission propulsion exercise to “our” asteroid without ever getting outside the Earth/Moon system
- Phobos and Deimos as former NEAs parked in areocentric orbit

Benefits of Asteroids Near the Moon

- Asteroid contribution:
  - Chemical Reagents for Lunar Surface Processing
  - Propellants for Lunar Landing and Departure
  - Staging point for deep-space manned missions that removes need for a lunar polar base (water!)

Rôles of Private Enterprise

- Low-cost *competitive* access to space
- Large-scale *competitive* mineral exploration
- Efficient, *competitive* resource exploitation
- Construction and operation of communication and transportation hubs (LEO, GEO, HEEO, lunar L1, LLO etc.)
- Political appeal for both parties

We CANNOT AFFORD a centrally-controlled, duplication-free, government-dominated effort

A New, Broader Perspective

(Back to the Future of Tsiolkovskii and Goddard)