Resource Potential of Asteroids

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Outline of Topics

- Near Earth Objects (NEOs): asteroids and comets
- NEO population characteristics
- NEO resource potential: accessibility, size, composition, physical properties
- What is learned from remote sensing and from spacecraft visits
- Knowledge requirements for resource exploitation, and need for precursor missions

Resource Potential

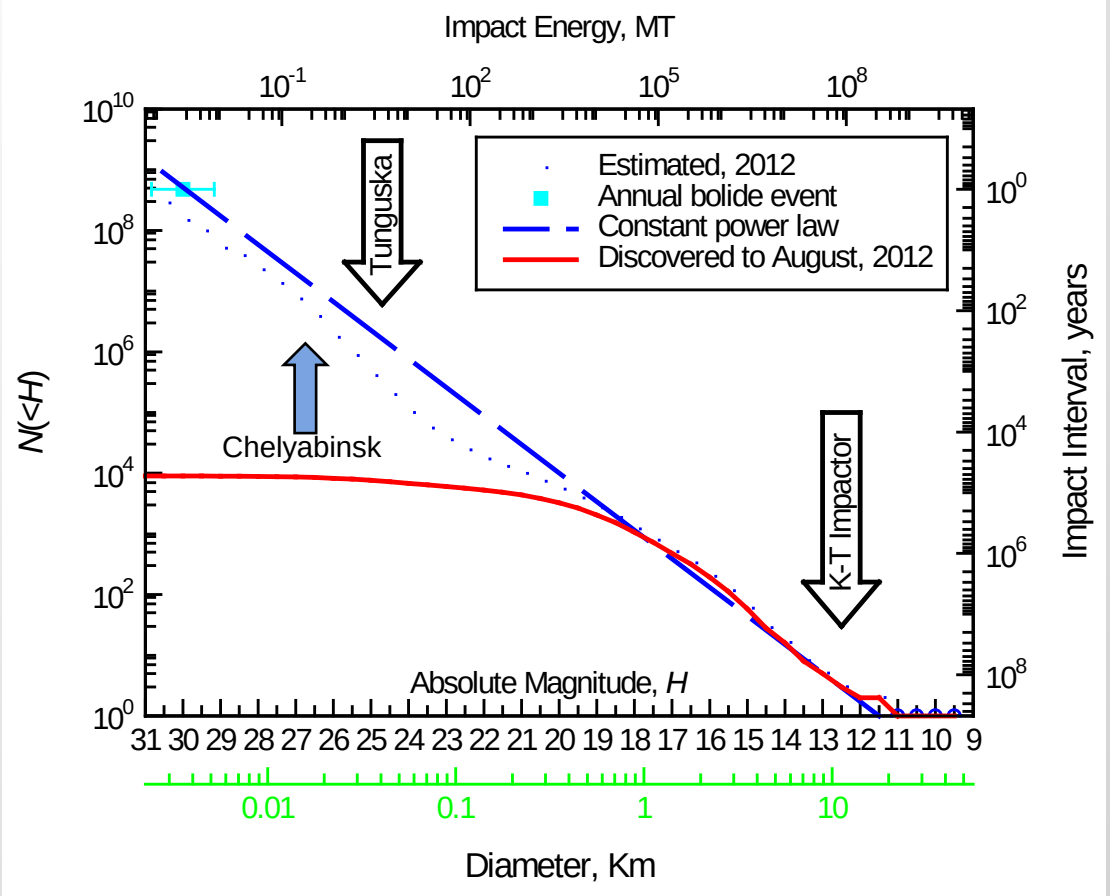
- **Resource potential depends on asteroid characteristics**
- **Accessibility**
  - **cost or difficulty to go there**
- **Size**
  - **how much of the resource may be present**
- **Composition**
  - **how much of the resource may be present**
- **Physical Properties**
  - **cost or difficulty to extract or exploit resource**
- **How can we determine characteristics defining resource potential?**

Near Earth Objects

- NEOs are the small bodies of the Solar System that come within 1.3 AU of the Sun
  - They are asteroids and comets
  - The largest two NEOs are Ganymed (32 km) and Eros (20 km)
  - The smallest NEOs account for most of the number of objects
- The largest NEOS contain most of the mass in the Near Earth population
- The total population of NEOs larger than a km size is about 900 objects
  - Over 95% of NEOs this large have been discovered
- More than half of NEOs larger than 300m size have been discovered
  - Less than 1% of NEOs larger than 30 m have been discovered

Near Earth Objects

- The NEOs (of H ≤ 22) whose orbits come within 0.05 AU of Earth's orbit are called Potentially Hazardous Objects
  - Objects the size of the Chelyabinsk impactor impact Earth every few decades
  - Dust impacts on Earth at 100 tons per day
  - Larger NEOs are fewer in number, and hit Earth less often
- The most numerous NEOs are small



Accessibility and Size

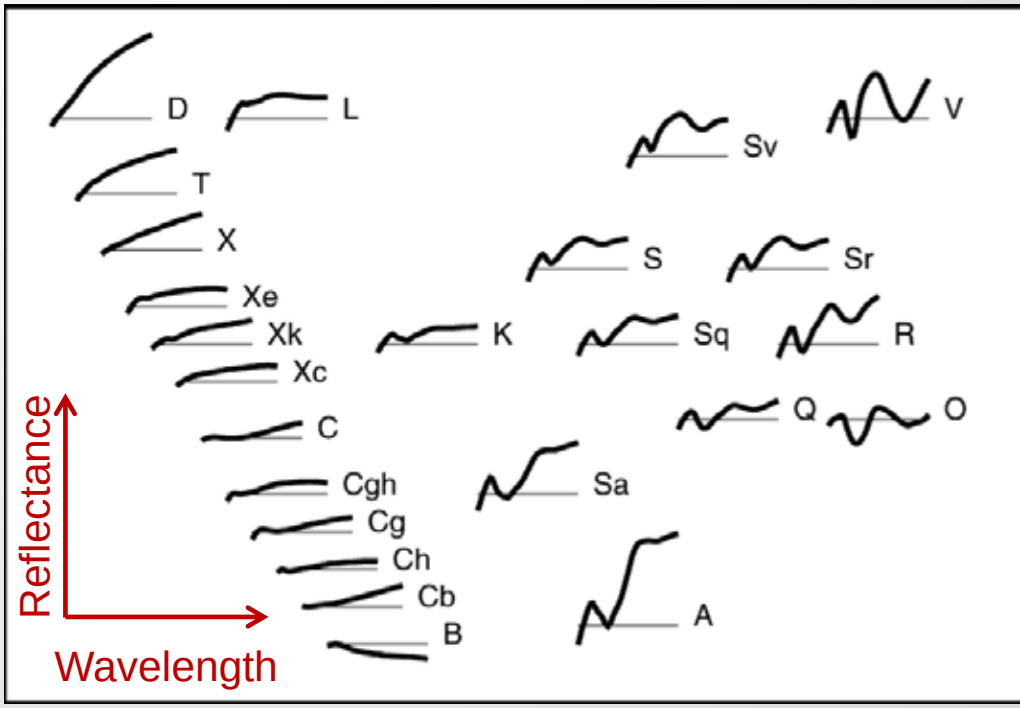
- NEOs vary widely in accessibility, from excellent to frightful
  - Round-trip delta V (parking orbit to rendezvous and return)
  - Trip duration
  - Stay time at asteroid
- The most accessible NEOs tend to be very small
  - Top 50 most accessible targets in NHATS have median H=27.6 (smaller than the Chelyabinsk impactor, about 10 m diameter)
  - See neo.jpl.nasa.gov/cgi-bin/nhats

Composition

- **Composition is measured from dust and meteorites recovered at Earth**
  - **Material of asteroidal and cometary origin**
- **Composition is inferred from remote sensing**
  - **Visible and infra-red spectra**
  - **Radar backscatter properties**
  - **For the vast majority of known NEOs, there is no available information on composition**
- **Composition inferred from spacecraft visits**
  - **Rendezvous missions NEAR and Hayabusa to asteroids Eros and Itokawa, respectively**
  - **Eros and Itokawa are S-type asteroids (stony, chondritic)**
  - **Planned sample return missions OSIRIS-REx and Hayabusa-2 to C-type asteroids Bennu and 1999JU3, respectively (more watery and less metamorphosed than S-type, but also chondritic)**

Composition and Spectra

- Asteroids are classified according to visible spectral characteristics
- Various classification systems are in use
- Can define broad "types" or "complexes", including "C", "S" [also "D" and "X"]
  - "C" spectrally similar to carbonaceous chondrite meteorites; dark [low albedo]
  - "S" spectrally similar to ordinary chondrite meteorites or to achondrites; bright
  - "D" and "X" for another time
- The most common NEOs are in the "S" complex
  - Large observational biases



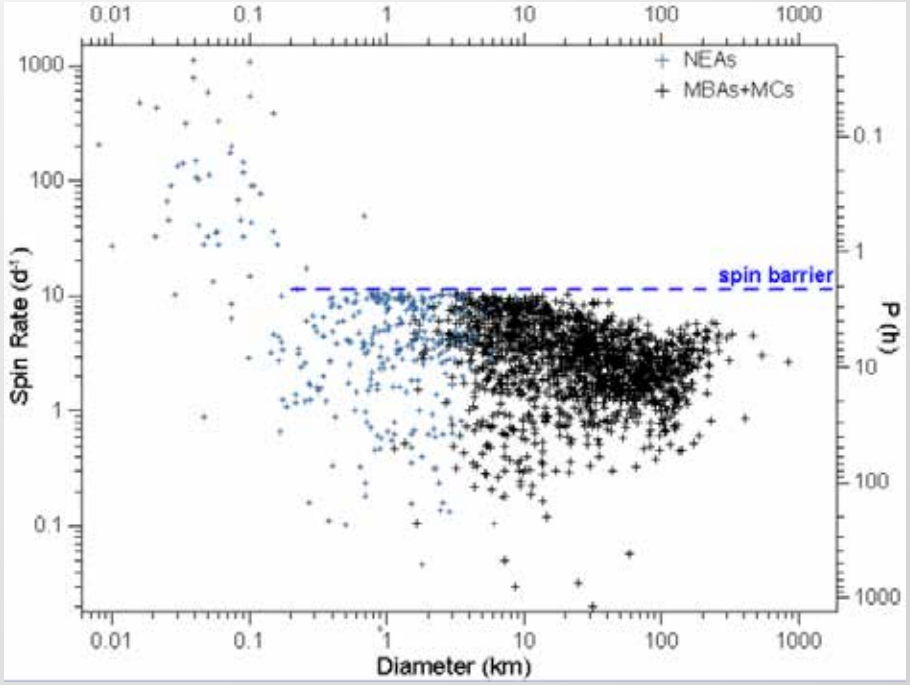
Composition and Potential Resources on NEOs

- Chondritic materials are those which the element abundances match those found in primitive meteorites (specifically, chondrules in those meteorites)
  - These are also cosmic (solar system) abundances of elements aside from losses of volatile elements
- Chondritic materials ("C" and many "S" asteroids) are rich in gold and platinum group elements
  - Precious metals average 1000x more than in average Earth crust
- The chondritic "S" asteroids are rich in free iron-nickel metals, also in sulfides, less tightly bound than oxides
  - Based on chondritic meteorites, free iron can be more than half of all iron and iron sulfide can be several wt% of total
- Many asteroids, of the dark ("C", "D") complexes, are rich in hydrated minerals
  - Water can be >10 wt% and bulk carbon can be up to 5 wt%
  - Organics not yet confirmed for NEOs

Physical Properties, Object as a Whole

- **Mass, Density and Rotation of the asteroid are important for**
  - Difficulty of proximity operations and landing
  - Difficulty of ascent and return
- **Mass and density (or mass and size) determine the time scales of operations and the propulsion requirements**
  - Mass is directly measured for only 2 NEOs, Eros and Itokawa
  - Mass is inferred for binary NEOs (few dozens known)
- **Rotation**
  - Rotational “spin barrier” for sizes larger than 200 m

Small NEOs are fast rotators

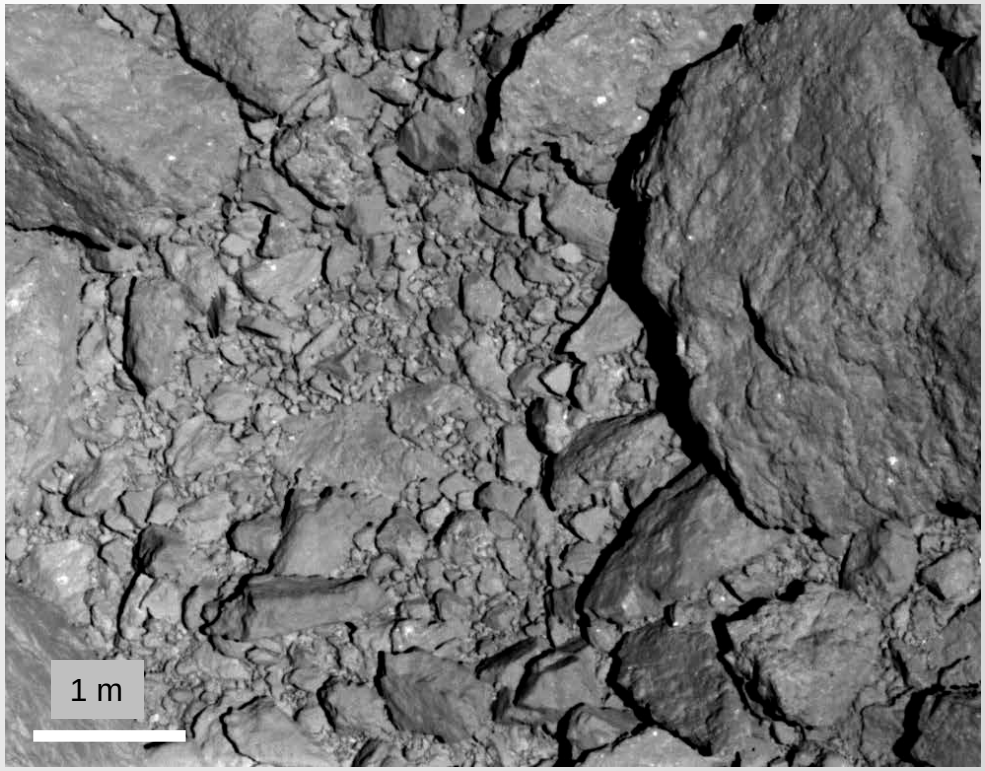


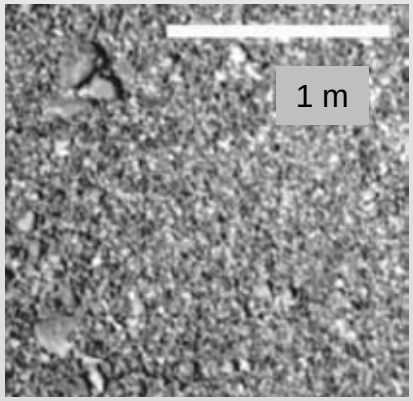
Physical Properties, Surface of Asteroid

- **For resource utilization, mechanical and thermal properties of the asteroid surface are needed**
- ***Mechanical* properties of the surface:**
  - **Strength (cohesion, crushing, penetration and shear)**
  - **Porosity**
  - **Particle size distributions**
- ***Thermal* properties of the surface**
  - **Temperature distribution across surface**
  - **Variation of temperature with local time and latitude**
  - **Thermal inertia, heat capacity, skin depth**

Other Knowledge Requirements

- **Shape model and topography of asteroid**
  - **Are blocks or boulders present?**
  - **What is the state of sedimentation?**
- **Dust environment of asteroid**
  - **How readily is dust lifted from surface, and how long will dust remain above the surface?**
- **Is the asteroid a binary or multiple system?**





Itokawa, rough and smooth areas

Knowledge Needs for Resource Potential

- **Accessibility**
  - **The known accessible objects are tiny**
  - ***NEO survey is needed***
- **Size**
  - **Only limited information available from thermal IR observations**
  - **Radar measurements only if object passes close to Earth**
- **Composition**
  - **Limited information available from spectral observations**
  - **Some potential resources not assessed by spectral observations**
- **Physical properties**
  - **Mass, Density: limited information if observed as binary (mostly radar)**
  - **Surface properties: limited thermophysical data from remote sensing**
- ***Precursor missions are needed to assess resource potential***