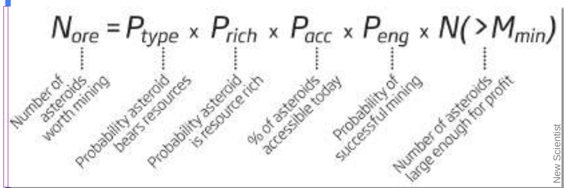
How Many Ore-Bearing Asteroids?

Martin Elvis[1],

1. Harvard-Smithsonian Center for Astrophysics (CfA),

email: melvis@cfa.harvard.edu

LPSC-2014-1048



Elvis, M., 2014, Planetary & Space Science, 91, 20

The Factors

- Follow Drake Equation formalism of multiplicative factors:
- Total number of NEAs with mass > M_{min} for profit
- Then determine number of the right resource richness,
- i.e. the right spectral type (P_{type})
- and high resource concentration within that type (P_{rich})
- that are also in accessible orbits (P_{acc})
- and are mineable (P_{eng})
- P_{rich} is poorly determined from meteorite samples.
- ~1000/(>20,000) NEAs have a spectral type

ABSTRACT

•A simple formalism is used to estimate the number of ore-bearing (i.e. **profitable**) near-Earth Asteroids

•Only a small fraction, and a small number, of all NEAs will be profitable to early mining ventures.

•Telescopic techniques are essential to sieving the NEA population to find these few.

•This information will be valuable.

• All the numbers are highly uncertain

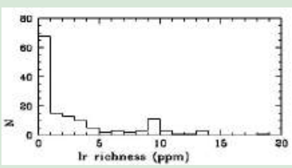
•**Much more research is needed** ☺

Assessing the Terms

Platinum Group Metals: P_{type} x P_{rich}

P_{type}

- Several sources.
- Richest likely M-type ~pure Ni-Fe
- M-type + ~27% of X-type are 4% of NEOs (Binzel et al. 2004)
- **P_{type}(PGM) = 4%**



Distribution of Iridium (Ir) fraction in type IIIAB meteorites (data from Scott et al. 1973) [latest available !]

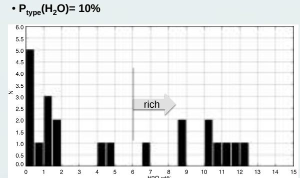
P_{rich}

- Wide range in PGM concentration [C_r(PGM)] for Ni-Fe meteorites
  - 0.01 – 100ppm (Kargel 1994)
- Ir correlates with other PGMs, better measured.
  - C_r(PGM) ~ 7 C_r(Ir)
- Terrestrial Pt mines have C_r(PGM)~2-6ppm
- All NEOs with C_r(Ir)>1ppm beat terrestrial mines
- **P(C_r(Ir)>1) = 50%**
- Note that P(C_r(Ir)>5) = 25% - *MUCH* better targets
- N(D>60m) ~ 200,000? (highly uncertain)

Water: P_{type} x P_{rich}

P_{type}

- Carbonaceous only likely source
- C-type 9.8±3.3% of NEOs (Stuart & Binzel 2004)
- **$P_{type}(H_2O)$= 10%**



H_2O by percentage weight (wt%) for Carbonaceous chondrites (Jarosewich 1990)

P_{rich}

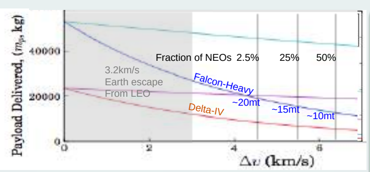
Hydrated minerals

- e.g. clays
- ranges from <0.1%wt to 12%wt. 2 groups? ><6%wt
- take C_r(hydrated) = 10%
- 31% have >6%wt (Jarosewich 1990)

Ice

- only stable at ~1AU if shielded
- brine found in meteorites (Saylor et al. 2001)
- C_r(Ice) depends on **macro- and micro-porosity**
- micro-porosity wide range 1-20% (Britt & Consolmagno 2003)
- macro-porosity *highly* uncertain: eg, 28±37% (3671 Dionysus Carry 2012)
- take C_r(Ice) = 10%.
- **$P_{rich}(H_2O)$ = 25%** (Jarosewich 1990)

Orbital Accessibility: x P_{acc}



delta-v:

- Water needs handling of ~1200mt to reap $1B of H_2O (@$10k/kg in LEO, 20% H_2O)
- PGMs need handling ~2 *million* mt for $1B.
- So expect mining equipment to be massive
- Payload drops rapidly with larger delta-v
  - E.g. Elvis et al. 2010, Planetary & Space Science, 59, 1408; Elvis & Ranjan in prep.
  - e.g. Space-X Falcon-Heavy will put 54 mt in LEO
  - but only ~10mt to median delta-v NEO (incl. upper stage)
- 1st mining targets like ultra-low delta-v
- **P_{acc} = 2.5%**

Bottom Line: *How many ore-bearing asteroids?*

Platinum Group Metals:

P_{type}x P_{rich}x P_{acc} = 0.04x0.5x0.025
= 5x10^{-4} = ***1/2000***

Need >100m dia for $1B, N=20,000

N=10

Could be **N=100** for delta-v=5.5km/s
or **N=50** for C_r(Ir) > 5 ppm, 50m dia.

Water:

P_{type} x P_{rich} x P_{acc} = 0.1 x 0.31 x 0.03
= 9x10^{-4} = **1/1100**

Need >20m dia for $1B, N=$10^7$

N=9000

But 20m dia hard to find
V<20 seen only at <0.04 AU (<15.4 lunar distance)
N~2000 @ 50m dia.

Neglects engineering issues, imperfect retrieval efficiency

How to Do Better:
More research is needed. Specifically:

P_{acc}

- Evaluate real mission profiles (e.g. NHATS)
- Consider:
- high power Solar electric (e.g. 50kW for ARM)
- novel return trajectories 10X lower delta-v (Sanchez & McInnes 2011). Slow?
- alternative destinations to LEO, direct Earth-entry

$N(D>D_{min})$

- Steep rise from 20,000 @ 100m to 10 million @ 20m
- Need deeper high cadence survey to find ~50m dia. NEOs, establish normalization, slope.
- then larger survey to catalog large fraction

P_{type}

- Only ~1000 NEO spectra known
- Need factor 10 scaling up of rate
  - see *LINNAEUS* Poster #1047
- Meteorite-Asteroid links are weak:
  - Find more2008 TC3 "*death plunge*" (small) asteroids
    - needs sensitive high cadence sweet spot surveys
  - Return more samples (e.g. Hayabusa II, OSIRIS-Rex, Marco-Polo-R) – *cheaply!*

P_{rich}

- Too few meteorites assays
  - collect literature
  - assay more!
- Improve Meteorite-Asteroid type links
  - see P_{type} (*left*): more 2008 TC3's
- MANY in situ probes
  - in plans of Planetary Resources, Deep Space Industries
  - need ~dozen probes @ P=0.25 to find 1 at 95% confidence (Elvis & Esty 2014 Acta Astronautica 96, 227)

P_{eng}

- Serious analysis, study
  - anchoring, digging (granular physics, Daniels 2013)
  - extraction
- Practice techniques in space
  - first on ISS (small scale, ~kg)
  - then on retrieved asteroid (~7m class)
- argues for Asteroid Redirect Mission (ARM) (Brophy et al. 2010)