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Asteroid Mining Concepts

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Neil Armstrong, the very first human to step on the Moon, would never have predicted the advancements, ramping human interest, opportunities and sheer aspirations contained within the contemporary space community, accelerating space exploration at the technological pace it has since that landmark day for humanity in July 1969.

One such phenomena he wouldn't have likely considered is that of space asteroid mining, which details the extraction of raw materials from any given asteroid or moon identified as a viable target. Though this concept sounds new to many, it's been around for decades. These days, asteroid mining is no longer a mere dream.

Over a thousand million asteroids are present in space near the Earth. As we've established, these space rocks are also called near-Earth asteroids (NEAs), rich in mineral deposits and, with any luck, water. The relative proximity and abundance of these rocks makes asteroid mining a viable enterprise. That's the reason big corporates are getting drawn into a potentially risky but extremely lucrative industry. The funding for mining ventures has already begun and commercial prospecting missions are expected to begin as early as 2020.

Though it sounds like the type of science fiction resigned to a poster on a teenager's bedroom wall, asteroid mining is rapidly becoming a workable niche industry within the new space economy. This economy also features space tourism and colonization as vital components. Whilst the logistical

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challenges are substantial, early stage ventures are filtering down necessary technologies required for commercial positioning, so tangible operations, both economically and technologically, are not insurmountable.

Excavating an asteroid for resources would in theoretical concept function very much like terrestrial mining—except for lacking the environmental concerns integral to Earth-based practices. And an atmosphere; and gravity! But that's not putting companies and nations off. There are "lots and lots and lots" of US dollars out there according to a November 2017 report by web portal Visual Capitalist.

If humans were able to get their hands on just one asteroid, it would be a game changer. That's because the value of many asteroids is measured in quintillions of dollars, telephone numbers if you will, which makes the market for Earth's annual production of raw materials, at about US$660 billion per year, look paltry in comparison.

The reality is that the Earth's crust is saddled with uneconomic materials, whilst certain types of asteroids are almost pure metal. X-type asteroids, for example, are thought to be the remnants of large asteroids that were pulverized in collisions in which their dense, metallic cores got separated from the mantle, according to Virtual Capital.

And whilst asteroids are composed of a variety of compounds, there are a few that are of specific concern to prospectors, specifically hydrogen, water and platinum-group metals. The basic concept is to mine material from NEAs, those having orbits that come near the Earth, a set quite separate from the main belt asteroids that orbit between Mars and Jupiter.

Resources mined from the asteroids could be exploited in space to support space flight, space stations and potentially a lunar base. The most valuable material for these claims would likely be water, gases such as Methane or other compounds that could be either utilized as space rocket fuel or exploited to replace the consumable materials needed for sustenance and sustainable life. Some scientists have proposed that the metals in asteroids, such as iron and nickel, might also be extracted as raw materials for extracurricular space operations.

The other key purpose of mining asteroids would be to bring precious metals back to the Earth, which, as has been commented on previously, would have a drastic effect on commodity market prices. The most likely metals to extract would include the rare and expensive platinum and platinum-group precious metals as well as gold. Astronomers have confidence that an A-typical asteroid should have much higher quantity of these metals than usual rocks on Earth or even on the Moon.

In the past, asteroid-mining concepts required individuals to visit the asteroids and mine them, but now contemporary schools of thought have postulated innovative ideas that involve strictly robotic operations. One option would be simply to bring portions of the asteroid back to Earth and disassemble them in areas where a processing plant could be set up. Other ideas detail dropping segments of the asteroid on the Moon or treating materials in-situ, on the asteroid itself, perhaps bringing it into orbit around the Earth for this process.

The technology required to go to NEAs is to all intents and purposes established, bolstered by the fact that the amount of rocket power and fuel quantities required to go to a number of these astral bodies is less than it takes to travel to the Moon. And we've done that already.

In contrast, the technology necessary to mine them and generate usable materials has, as yet, not been developed. And it's not clear as to how tough and expensive this might be, neither is it apparent whether the task may well be conducted using robots or via systems requiring human remote oversight.

Back to the top and we see that articles regarding asteroid mining have appeared in magazines and the goliaths of business news television like Bloomberg, which has already interviewed astronomers and commodity specialists regarding the subject of space mining and its viability and development.

Originally, the concept of asteroid mining was primarily based on the history of the mining and oil industries. It had been assumed that investor-funded exploration of NEAs would begin first, followed by a small group of trained 'traveller–miners' being transported to and from the NEAs to partake in exploratory mining missions. Once the method for asteroid mining became standardized, then 'hyper-corporations' would send many trained traveller–miners deep in to the Asteroid Belt, where they would work and sleep for years before returning to Earth.

However, this concept of an asteroid-mining trade raised many queries, because, as has been discussed, humans are very delicate and their needs to function are immense in comparison to that of a 'well-oiled machine'. Why send many individuals to mine asteroids when robots can be designed to try to do it?

It is of notoriety that, whilst NASA and others are working on the problem, we still have unresolved issues regarding long-term zero gravity exposure for any human astronaut miners. Currently, Astronauts who stay for three months or longer on the International Space Station (ISS) report changes in their eyesight in zero gravity and also atrophy, where muscle-mass wastage sets in, causing limbs and muscles to degrade and weaken. Before humans can venture into deep-space operations with associated long-haul space flights and protracted periods of habitation, we first need to solve issues of zero gravity, perhaps developing our own artificial gravity to replicate conditions on Earth, such as rotating structures mimicking our Earth's spin of a scalable 1,000 miles per hour.

If the technological obstacles to actual asteroid mining are effectively overcome, that is, digging the stuff out, it could be supposed that an individual will be able to sit in front of a display and guide a robot in to deep space; trace and perform spectrum analysis of said asteroid; mine the asteroid for materials whilst the mining bot is tethered to a small spacecraft and pack the harvested materials into the spacecraft, before navigating the spacecraft to a crewed space station that serves as a collection point. From thereon in the materials would be processed whilst still in deep space.

To this end the agenda of so-called hyper-corporations would be to gather, sort and transport large quantities of asteroid constituents from the Asteroid Belt to the Earth or the Moon for onward sale and consumption.

Asteroid Composition

S-Type. These asteroids carry lesser quantity of water but appear more striking because they comprise various metals including nickel, cobalt and more valuable metals such as gold, platinum and rhodium. A minor 10-metre S-type asteroid contains about 650,000 kilograms (1,433,000 pounds) of metal with 50 kilograms (110 pounds) in the form of rare metals like platinum and gold.[1]

C-Type. These are the most common type of asteroids and comprise more than 75 percent of known asteroids. They also have a high abundance of water, which is not currently of use for mining but could be used in an exploration effort beyond the asteroid. Mission costs could be reduced by using the available water from the asteroid. C-type asteroids also have a lot of organic carbon, phosphorus and other key ingredients for fertilizer, which could be used to grow food.

M-Type. These asteroids comprise nickel and iron but are the least abundant. A very small percentage of asteroids fall in this category.

A burgeoning, sophisticated global society is stimulating an increasing demand for rare minerals and precious metals. However, there's a restricted

[1] Space.Com, By Charles Q. Choi, 20 September 2017, "Asteroids: Fun Facts and Information About Asteroids", https://www.space.com/51-asteroids-formation-discovery-and-exploration.html

quantity supplied of such materials buried within the Earth and acquiring them in even minute quantities is costly. If these materials can be nonheritable in giant quantities, then makers may lower the per-unit price of high tech product, thereby counterintuitively increasing profits by lowering net worth and increasing demand.

Mining and Processing

First, mining can be simply conducted by bringing the asteroid raw material back to the Earth.

Second, processing the raw material on site and bringing back only the processed material (and therefore also producing propellant for a return trip) has been established as a feasible scenario.

Processing in-situ with the aim of extracting high-value minerals can scale back the energy needs for transporting the materials, though the processing facilities should first be transported to the mining location.

Mining operations need special instrumentation to handle the extraction and process of mineral ores in space. The machinery can be anchored to the target, however, once on site, the ores would be expedited because of the shortage, or entire lack, of gravity, depending on the size of the rock or whether an asteroid of near-planetary proportion is being mined.

However, quite a lot of work still needs to be done to perfect techniques for refinement of ores in a zero gravity or low gravity environment. Tethering with an asteroid could be performed by employing a harpoon-like method, where a projectile would penetrate the surface to function an anchor; then a cable would winch the vehicle to the surface assuming the asteroid is both penetrable and rigid enough for a harpoon to be effective.

Due to the distance from Earth to a given asteroid identified for mining, the 'bounce-time' for communications will feature a significant delay, all be it a matter of minutes, it is still of great significance and a challenge when designing systems.

So, any mining paraphernalia will need to be highly automated or a human being is going to need to govern operations. Humans would also likely be useful for fault diagnosis, troubleshooting and maintaining the equipment. Still, 'multi-minute' communications delays haven't prevented the success of the robotic exploration of Mars, and automatic systems would be a lot less costly to create and deploy for muted mining missions.

Asteroid Extraction Techniques[2,3,4]

(a) Surface reclaim with ‘snowblower’:
  Advantages—robust process; easy to handle loose soil; easy to monitor.
  Disadvantages— problems with anchoring and containment; surface will be desiccated.
(b) Solar bubble vaporizer:
  Advantages—simple, collects volatiles only.
  Disadvantages—unacceptably high membrane tension; how to seal? How to anchor?
(c) In-situ volatilization:
  Advantages—simple concept; asteroid body gives containment.
  Disadvantages—needs low permeability; risks are loss of fluid; clogging; and blowout.
(d) Explosive disaggregation:
  Advantages—very rapid release of mass, short timeline.
  Disadvantages—capture of material is unsolved.
(e) Downhole jet monitoring:
  Advantages—mechanically simple; separates mining from processing task.
  Disadvantages—need gas to transport cuttings to processor; blowout risk high.
(f) Underground mining by mechanical ‘mole’:

Advantages—reduced anchoring and containment problems; physically robust.

Disadvantages—mechanically severe; hard to monitor; must move cuttings to surface plant.

Surface mining: on some forms of asteroids, materials could also be scraped off the surface by employing a scoop or auger, or for larger items, an ‘active grab’. There’s solid proof that several asteroids contain sizeable dust piles indicating this type of approach as being possible.

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[2] University of Wisconsin, Madison, Department of GeoScience, accessed on 19 April 2018, “Extraction Techniques for Minerals in Space”, http://www.geology.wisc.edu/~pbrown/spacemine/spacemine.html

[3] Department of Physical Geography and Ecosystem Science, Lund University, By Vide Hellgren, June 2016, “Asteroid Mining A Review of Methods and Aspects”, https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8882371&fileOId=8884121

[4] MIT, “Asteroid Mining”, accessed on 19 April 2018, http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/asteroids.html

Magnetic rakes: asteroids with a high metal content, also lined with loose grains and seams could be gathered by using a magnet.

Mond Process: The nickel and iron of an iron made asteroid can be extracted by the 'Mond Method'. The Mond Method, which is sometimes known as the 'Carbonyl Process', is a technique created by Ludwig Mond in 1890 to extract and purify nickel. The method was used commercially before the end of the nineteenth century on Earth. The process is repeated to get metal in a highly pure state. Nickel and iron may be retrieved from the gas once more at higher temperatures, much like a reverse refinery where cooling towers harvest liquids from a gaseous state here on Earth, then—in theory— when connected to a 3D printer you can manufacture items from the residue.

Shaft mining: a mine is conduit into the asteroid and materials are extracted through the shaft. This needs precise geological information to engineer the accuracy of the location beneath the surface and a facility to hold the retrieved ores for the process facility.

There also are some fascinating opportunities relating to the generation of electric power from space resources. The options here include the development of solar-power satellites in high orbits that will beam solar energy down to the surface via microwave energy.

The retrieval of helium from the surface of the Moon could also be economically engaging as a supply of fresh fuel for fusion power reactors on the Earth or for fusion on the Moon, with the ability to then transmit energy straight down to the planet. Similarly, solar collectors could also be designed on the Moon out of native materials to send their power back to the planet.

The construction of solar-power satellites, not to be mistaken with 'solar-powered satellites', could in theory take place in space itself, providing a progressive, less expensive build if the high-mass, low-tech elements of the power satellite are made-up off planet. This could be said of any space vehicle. Propelling mass over gravity and air resistance requires a huge explosion of energy, which is ultimately expensive to manufacture.

Looking further afield, the helium three and hydrogen atom contents of the large planets are so immense that schemes for extraction and retrieval of fusion fuel from their atmospheres, especially Uranus and Neptune given their geological makeup, have been suggested as being capable of powering the world till our Sun dies of maturity.

The most economical sources of space materials are those bodies that have the best richness of valued commodities that are most accessible from Earth.

Argon is particularly of current importance for the terrestrial metal industry, being used as an inert gas shield in arc welding and cutting. Other applications include non-reactive blankets in the manufacture of titanium and other reactive elements and as a protective atmosphere for growing silicon and germanium crystals. It is one of the noble gases, which are catalogued as Group 0 on the periodic table. Argon makes up about 0.9 percent of our air. The group consists of He—helium; Ne—neon; Ar—argon; and Kr—krypton.

Asteroid Mining System Program (AMSP) Risk Domains

Cost risk: the ability of the system to accomplish the programme's life-cycle value objectives. This includes the consequences of budget and affordability selections and also the effects of inherent errors within the value estimating technique(s) used, provided that the system needs were properly outlined.

Technology risk: the degree to which the technology planned for the system has been assessed as being capable of meeting all of the project's objectives.

Performance risk: the degree to which the projected system or method is capable of meeting the operational needs that embody responsibility, maintainability, reliability, accessibility and testability needs.

The most relevant consideration in quantifying performance of the asteroid mining mechanism is handling the asteroid's rotation. Scientists believe the answer to this downside is to connect rockets to the asteroid so as to counteract the direction of its spin. In other words, if the asteroid spins dextrorotary, the rockets can stabilize the asteroid by pushing it counter clockwise.

Mission assurance risk: the degree to which existing and potential deficiencies could pose a threat to system safety or jeopardize mission-critical components. Deficiencies embrace damage-causing hazards; mission-impacting failures; seepage from unaddressed requirements; ambiguous procedures; excessive environmental conditions; latent physical faults; inappropriate corrective actions; and operator errors.

Data access and protection risk: the degree to which essential knowledge—intellectual property—is protected from unauthorized access and guarded from loss, corruption or interruption. The operators of mining robots will

Table 6.1 Organizations involved in asteroid mining

Organization	Type
Deep Space Industries	Private company
Kepler Energy and Space Engineering	Private company
Planetary Resources	Private company

be required to be provided with secure, encrypted communication links to avoid, what is colloquially known as, 'hacking' for illegal agendas.

See Table 6.1 for a list of organizations that are involved in asteroid mining. Table 6.2 shows the Asterank database of potential targets as per most cost-effective asteroids.

Feasibility

There are six categories of cost considered for an asteroid mining venture:

(i) R&D costs
(ii) Exploration and prospecting costs
(iii) Construction and infrastructure development costs
(iv) Operational and engineering costs
(v) Environmental costs
(vi) Time cost

Ongoing missions include:

OSIRIS-REX— planned NASA asteroid sample return mission (launched in September 2016).

Hayabusa 2— ongoing JAXA asteroid sample return mission (arriving at the target in 2018).

Asteroid Redirect Mission— potential future space mission proposed by NASA (if funded, the mission would be launched in December 2020).

Fobos-Grunt 2— planned Roskosmos sample return mission to Phobos (launch in 2024).

Completed missions are shown in Table 6.3.

Table 6.2 Asterank Database: Potential Targets as per most cost-effective asteroids[a]

Name	Type	Value ($)	Est. profit ($)	Δv (km/s)	Group
Ryugu	Cg	82.76 billion	30.08 billion	4.663	APO (PHA)
1989 ML	X	13.94 billion	4.38 billion	4.889	AMO
Nereus	Xe	4.71 billion	1.39 billion	4.986	APO (PHA)
Bennu	B	9.05 billion	2.50 billion	5.096	APO (PHA)
Didymos	Xk	62.25 billion	16.39 billion	5.164	APO (PHA)
2011 UW158	Xc	6.69 billion	1.74 billion	5.189	APO (PHA)
Anteros	L	5.57 trillion	1.25 trillion	5.440	AMO
2001 CC21	L	147.04 billion	29.77 billion	5.636	APO
1992 TC	X	84.01 billion	16.78 billion	5.648	AMO
2001 SG10	X	3.05 billion	544.91 million	5.878	APO (PHA)
2002 DO3	X	334.44 million	59.00 million	5.897	APO (PHA)
2000 CE59	L	10.65 billion	1.80 billion	6.013	APO (PHA)
1995 BC2	X	78.87 billion	13.18 billion	6.016	AMO
1991 DB	C	168.20 billion	26.66 billion	6.148	AMO
2000 RW37	C	29.27 billion	4.53 billion	6.226	APO (PHA)
1998 UT18	C	644.70 billion	99.62 billion	6.221	APO (PHA)
Seleucus	K	33.52 trillion	5.02 trillion	6.287	AMO
1998 KU2	Cb	80.32 trillion	11.96 trillion	6.300	APO
1989 UQ	B	600.73 billion	87.58 billion	6.402	ATE (PHA)
1999 KV4	B	25.68 trillion	3.73 trillion	6.384	APO
1988 XB	B	217.07 billion	31.27 billion	6.415	APO (PHA)
1997 XF11	Xk	383.99 billion	52.97 billion	6.548	APO (PHA)
1997 RT	O	174.31 billion	24.21 billion	6.502	AMO
1996 FG3	C	1.33 trillion	181.33 billion	6.608	APO (PHA)
1992 QN	X	291.29 billion	39.63 billion	6.602	APO
1999 JV6	Xk	12.03 billion	1.59 billion	6.701	APO (PHA)
2001 TY44	X	3.50 billion	469.30 million	6.612	AMO
2002 EA	L	672.12 million	87.52 million	6.744	APO
2001 HK31	X	1.33 billion	172.74 million	6.723	AMO
2005 YU55	C	49.84 billion	6.23 billion	6.907	APO (PHA)
1992 BF	Xc	2.90 billion	357.72 million	6.982	ATE
2001 PD1	K	646.08 billion	80.62 billion	6.866	AMO
Lucianotesi	Xc	46.30 billion	5.66 billion	6.988	AMO
2002 CS11	X	766.16 million	94.49 million	6.918	AMO
1992 NA	C	3.96 trillion	476.47 billion	7.012	AMO
2002 BM26	X	77.75 billion	9.26 billion	7.073	AMO (PHA)
2002 AV	K	17.79 billion	2.12 billion	7.047	APO (PHA)
1999 NC43	Q	2.61 billion	307.48 million	7.126	APO (PHA)
2000 CO101	Xk	29.27 billion	3.39 billion	7.236	APO (PHA)
Dionysus	Cb	2.62 trillion	303.98 billion	7.182	APO (PHA)
1999 CF9	Q	152.75 million	17.53 million	7.247	APO (PHA)
2002 AH29	K	7.77 billion	892.45 million	7.212	AMO
1986 DA	M	4.25 trillion	484.67 billion	7.230	AMO
Davidharvey	C	53.90 trillion	6.14 trillion	7.237	AMO
1996 BZ3	X	73.17 billion	8.31 billion	7.254	AMO
2001 HA8	C	1.51 trillion	169.13 billion	7.319	AMO
Apollo	Q	805.03 million	88.33 million	7.486	APO (PHA)

(*continued*)

Table 6.2 (continued)

Name	Type	Value ($)	Est. profit ($)	Δv (km/s)	Group
2000 LC16	Xk	4.23 trillion	473.46 billion	7.325	AMO
2001 WH2	X	4.62 billion	497.01 million	7.547	AMO
2000 WC67	X	296.27 billion	32.12 billion	7.490	AMO
Atlantis	L	42.41 trillion	4.56 trillion	7.541	MCA
1998 HT31	C	10.42 billion	1.11 billion	7.590	APO (PHA)
2000 WJ10	Xk	3.50 billion	373.31 million	7.601	AMO
2001 HW15	X	3.50 billion	362.49 million	7.801	AMO
1999 VN6	C	62.78 billion	6.50 billion	7.787	AMO
2001 XS1	Cb	125.08 billion	13.15 billion	7.655	AMO
Eger	Xe	442.75 billion	44.75 billion	7.962	APO
Calingasta	Cb	18.08 trillion	1.87 trillion	7.764	MCA
Vishnu	O	242.46 billion	23.26 billion	8.356	APO (PHA)
2000 BG19	X	727.45 billion	74.70 billion	7.795	AMO
Zao	X	1.60 trillion	162.00 billion	7.885	AMO
1999 SE10	X	5.30 billion	547.05 million	7.750	AMO
1999 JM8	X	45.00 trillion	4.58 trillion	7.856	APO (PHA)
1994 AH2	O	21.02 trillion	2.11 trillion	7.952	APO
2000 WL10	Xc	80.47 billion	8.11 billion	7.907	APO
1997 SE5	T	66.28 million	6.74 million	7.826	AMO
2000 BM19	O	1.21 trillion	96.45 billion	9.949	ATE
1997 US9	Q	67.65 million	6.01 million	8.943	APO
2001 SJ262	C	30.61 billion	3.04 billion	7.984	AMO
Ra-Shalom	Xc	1.76 trillion	130.81 billion	10.649	ATE
1997 AQ18	C	286.95 billion	25.10 billion	9.072	APO
1999 HF1	X	9.21 trillion	556.48 billion	13.130	ATE
1999 YK5	X	7.66 trillion	475.70 billion	12.767	ATE
1999 JD6	K	4.77 trillion	254.78 billion	14.844	ATE (PHA)
2000 WO107	X	17.40 billion	726.21 million	18.990	ATE (PHA)
1997 AC11	Xc	2.92 billion	170.57 million	13.562	ATE
2000 EA107	Q	1.06 billion	61.22 million	13.755	ATE
2000 CK33	Xk	63.73 billion	4.55 billion	11.090	ATE
Poseidon	O	33.21 trillion	3.05 trillion	8.626	APO
2002 DH2	Ch	20.79 billion	1.96 billion	8.411	APO
Cruithne	Q	2.12 billion	117.66 million	14.240	ATE
1999 FB	Q	175.38 million	14.15 million	9.800	APO
2002 DY3	Xk	48.34 billion	4.31 billion	8.856	AMO
Izhdubar	Q	801.64 million	24.81 million	25.537	APO
2001 YK4	X	314.94 billion	29.45 billion	8.449	APO
2001 XS30	Xc	139.84 billion	7.00 billion	15.782	APO
2000 YH66	Xk	73.17 billion	4.62 billion	12.508	APO
David Hughes	Xe	12.14 trillion	1.11 trillion	8.634	MCA
Phaethon	B	> 100 trillion	5.30 trillion	15.344	APO (PHA)
Bede	Xc	11.47 trillion	1.04 trillion	8.661	AMO
Gressmann	B	81.81 trillion	7.76 trillion	8.314	MBA
2000 CN33	X	16.01 billion	1.51 billion	8.346	AMO
1995 BL2	L	261.02 billion	19.86 billion	10.364	APO

(*continued*)

Table 6.2 (continued)

Name	Type	Value ($)	Est. profit ($)	Δv (km/s)	Group
2000 BJ19	Q	2.42 billion	130.77 million	14.594	APO
2001 UY4	X	252.55 billion	18.59 billion	10.699	APO (PHA)
2000 WK10	X	48.34 billion	3.77 billion	10.096	APO (PHA)
2002 AU5	X	110.74 billion	9.60 billion	9.079	APO
Tantalus	Q	1.07 billion	35.86 million	23.458	APO (PHA)
Tapio	B	> 100 trillion	> 100 trillion	8.467	MBA
Heracles	O	> 100 trillion	30.31 trillion	9.641	APO

[a]Asterank, accessed on 19 April 2018, http://www.asterank.com/

Table 6.3 Completed missions

Nation	Flyby	Orbit	Landing	Sample return
 USA	ICE (1985)	NEAR (1997)	NEAR (2001)	Stardust (2006)
 Japan	Suisei (1986)	Hayabusa (2005)	Hayabusa (2005)	Hayabusa (2010)
 EU	ICE (1985)	Rosetta (2014)	Rosetta (2014)	
 USSR	Vega 1 (1986)			
 China	Chang’e 2 (2012)			

Additional Information Resources

https://en.wikipedia.org/wiki/Asteroid_mining

https://techcrunch.com/2016/02/03/the-race-to-mine-asteroids-gains-international-support/

https://www.scientificamerican.com/article/ive-read-references-in-bo/

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