A space-based gold rush

Ask someone about deep space mining ten years ago, and people would have looked at you with incredulity. Today, however, we're seeing the first companies pop into existence with just that in mind, while governments and associations the world over begin the onerous process of working out the legalities.

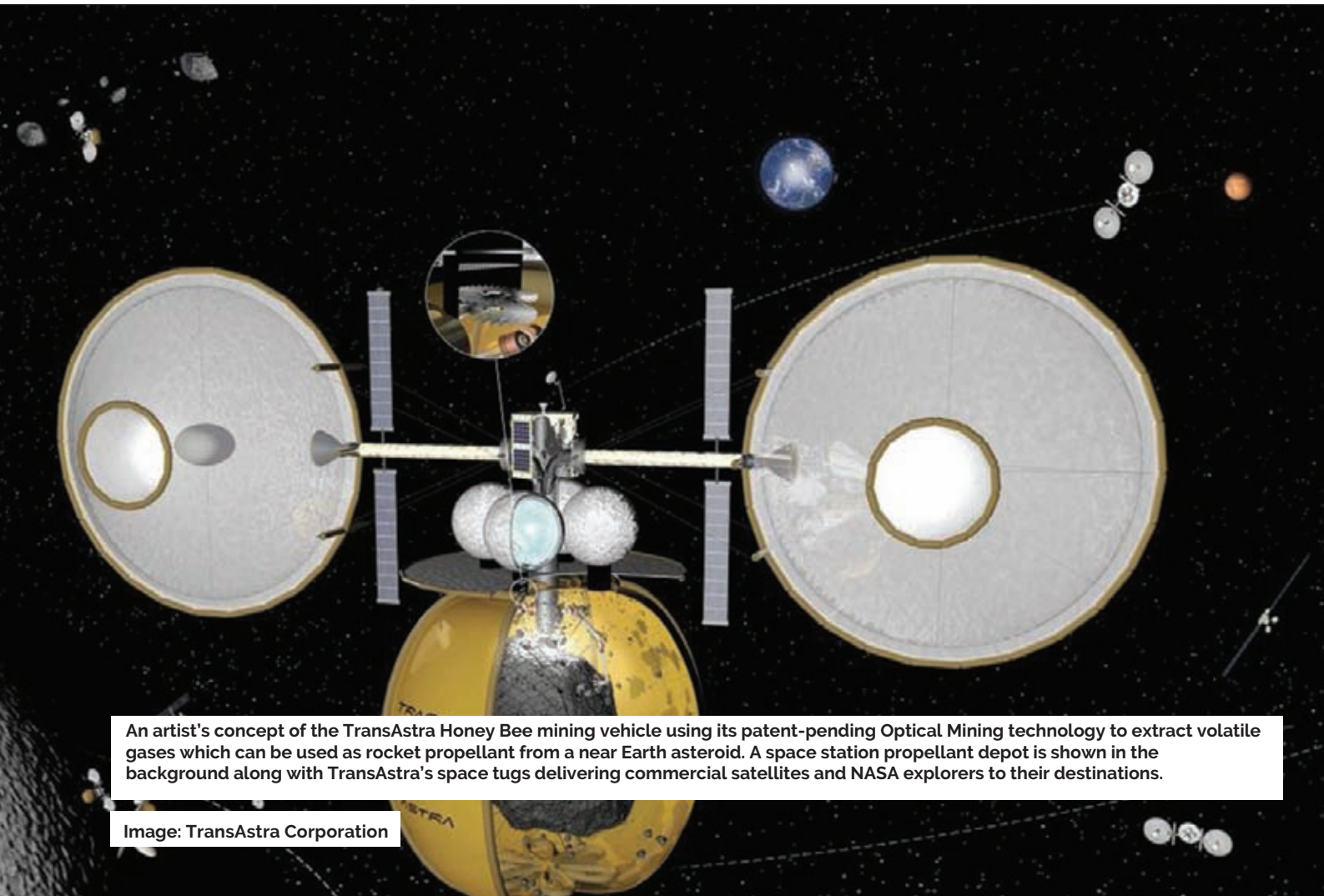
Deep space mining is a very modern solution to the old problem of resource depletion here on Earth. Whether we'll see successful space mining in our lifetimes – i.e. the cost-effective extraction of valuable elements from space, delivered back to Earth or else utilised in space – is yet to be established. There are several factors at play, and it's vital that we work out the financial, legal, technical, ethical matters ahead of any missions.

Cost is absolutely going to be a limiting factor. There's the development cost of spacecraft and suitable mining equipment, the cost to launch, costs related to telemetry and control, both in man-hours and more equipment, and the biggest cost of all: Returning mined materials to Earth (or perhaps an off-world base).

Then there's the legal implications. Deep space mining is covered by the Outer Space Treaty, which states that 'outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.' Indeed, the treaty allows for private property rights and exclusive ownership rights over natural outer space resources if removed from their natural place. In addition, some countries are launching their own acts. The 'SPACE Act of 2015' facilitates private development of space resources consistent with US international treaty obligations by recognising the right of US citizens to own space resources they obtain. Later in 2017, the Government of Luxembourg became the first European country to pass a law conferring to companies the ownership of any resource they extract from space.

Technologically-speaking, we've still a long way to go before we can successfully mine asteroids for anything. While a small number of missions have landed on ore-rich asteroids, the technology required to mine and refine materials from a moving asteroid, while maintaining (or creating from water) adequate fuel supplies to return those materials to Earth, remains beyond our reach. The alternatives to transportation back to Earth include transport to a nearby off-world base, or else utilising those mined materials in space, also require heavy technical development prior to becoming reality.

And then there's the ethics of it all. Just because we're depleting the resources naturally available on Earth, does that give us the right to mine other celestial bodies



An artist's concept of the TransAstra Honey Bee mining vehicle using its patent-pending Optical Mining technology to extract volatile gases which can be used as rocket propellant from a near Earth asteroid. A space station propellant depot is shown in the background along with TransAstra's space tugs delivering commercial satellites and NASA explorers to their destinations.

Image: TransAstra Corporation

for these precious materials?

Party balloons will be the death of us all

Resources here on Earth are finite, and we're fast running out of vital elements. Helium is one such element that us Chemists like to remind people about; it's vital for the operation of MRI scanners, cryogenics and NMR spectrometers, but it's relatively scarce on Earth, although there have been recent discoveries of new sources bringing us to around a 117-year supply. Despite this scarcity, helium is still freely available on the high street for filling balloons, something many scientists have taken umbrage with.

"I will not be happy if I cannot have a medical scan in my 70s, because we wasted helium on party balloons while I was in my 30s," said David Ward of the Culham Centre for Fusion Energy.

The second-most abundant element in the universe never reaches the Earth via solar winds because of our strong atmosphere, so there is no chance of natural replenishment. However, rocks brought back to Earth from the Moon contain around 22g of helium per cubic metre. "There is also hydrogen in that soil, which astronauts could use for fuel and to make water, so you could envisage the day when it becomes economic to build mines on the Moon to supply us with helium. It just depends how expensive our own sources become," Ian Crawford from Birkbeck College, University of London, told The Guardian.

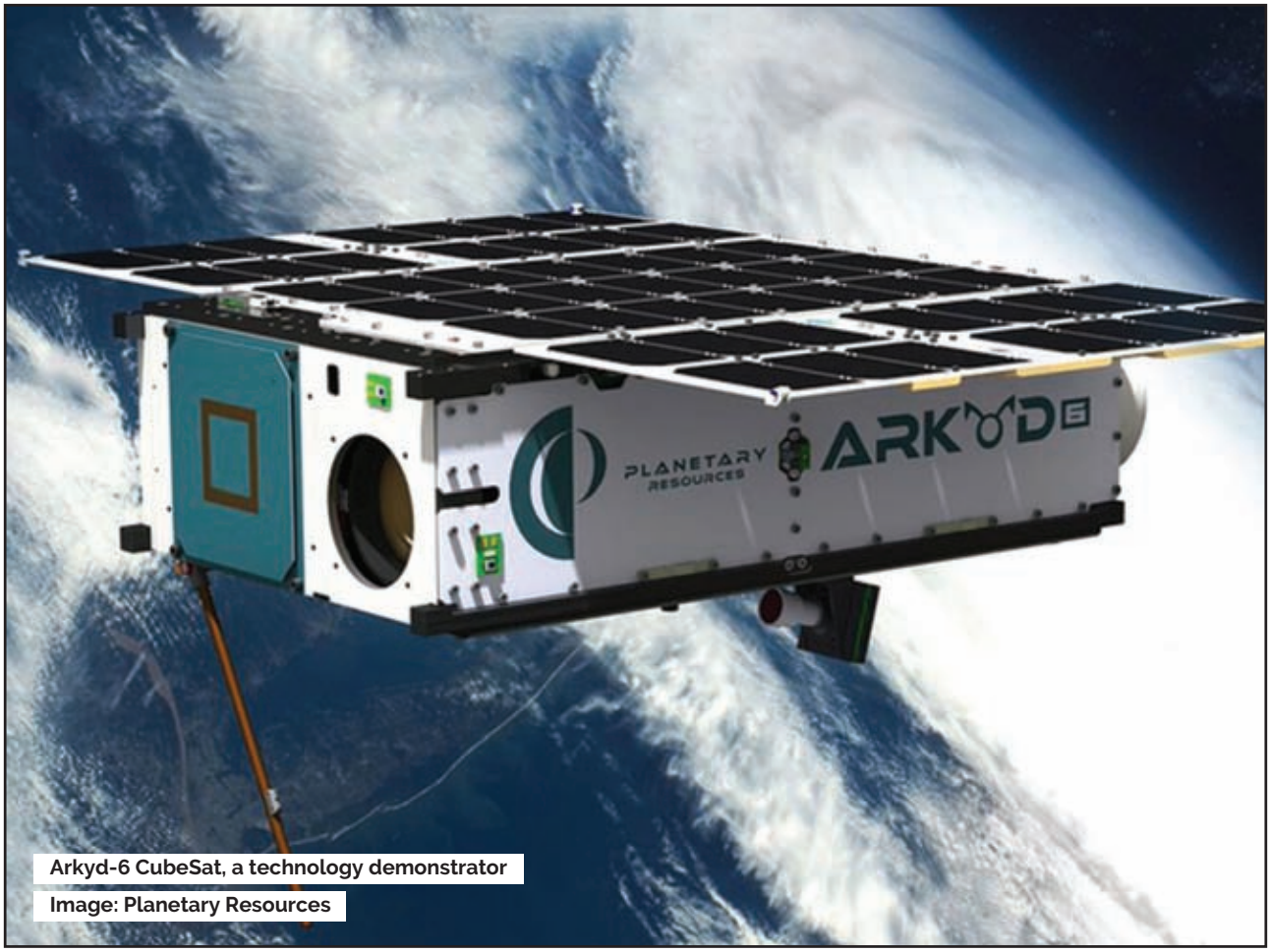
Of course, it's not just helium. Other elements such as copper, phosphorus, iridium, palladium, platinum, rhenium, ruthenium, gold, silver, iron, cobalt, tungsten, manganese, molybdenum, nickel, aluminium and titanium, are vital for modern life applications like medicine, construction, electronics, etc., are extremely limited on Earth, and far more freely available in space.

Who's getting in on the action?

Considering the high financial barrier to entry, there are quite a large number of companies getting in on the deep space mining game right now.

Planetary Resources' goal is to be a leading provider of resources for people and products in space by identifying, extracting and refining resources from near-Earth asteroids. As a first step, the company is seeking to identify and unlock asteroids with critical water resources, which are used for both life support and refinement into rocket propellant, necessary for human expansion in space.

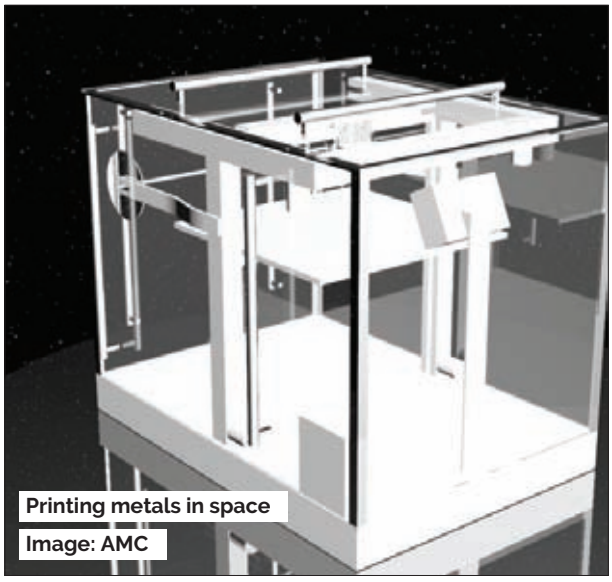
In January 2018, the company launched the Arkyd-6 CubeSat, a technology demonstrator designed to detect water resources in space. The Arkyd-6, which is fully-autonomous but communicates with Earth at every critical checkpoint, successfully demonstrated its distributed computing system, communications, attitude control system, power generation and storage with deployable solar and batteries, star tracker and reaction wheels, and the first commercial mid-wave infrared (MWIR) imager operated in space. The MWIR broadband imager spans 3-5 microns within the IR region, which is sensitive to the presence of water and thermal energy. During the mission, the MWIR was used to find the presence of water on Earth. The data obtained from this mission will be used in the development of the Arkyd-



Arkyd-6 CubeSat, a technology demonstrator
Image: Planetary Resources

Moon Express Lander One

Image: Moon Express



Printing metals in space

Image: AMC

301, Planetary Resources' next platform.

Once the company has its technology refined, it will deploy multiple spacecraft via a single rocket launch to pre-determined asteroids to collect data and material samples. Data collection will include global hydration mapping and subsurface extraction demonstrations to determine the quantity of water and the value of the resources available. The information gathered will allow Planetary Resources to design, construct and deploy the first commercial mine in space.

Deep Space Industries (DSI) is, alongside Planetary Resources, the other big name in deep space mining. The company plans to build a new type of spacecraft that drives down the cost of access to deep space, as much as 50 times lower than today's solutions. According to DSI, its spacecraft will grant private companies and government agencies access to high Earth orbits, Lunar orbits, near-Earth asteroids, Venus and Mars, helping unlock the commercial opportunities of space.

DSI has already developed the Comet system, a cost-effective electrothermal propulsion system for CubeSats and microsatellites that uses water as a propellant, available for sale for a unit price of US$200,000. Astro Digital and BlackSky have already signed deals to acquire several of the Comet systems from DSI. The next focus is the Xplorer spacecraft, a 12U CubeSat which is designed to use its own propulsion system to move from low Earth orbit (LEO) to an Earth departure trajectory. Xplorer is expected to become available in 2020.

Most recently, DSI closed the first tranche of its Series A funding round, having raised more than US$3.5 million from private investors. The funding will be used to continue the development of Xplorer and help develop the new launch-safe bipropellant rocket engine dubbed Meteor.

Moon Express is another major player in off-world resource acquisition, but with a focus primarily on the Moon, rather than the asteroids other companies are looking into. Moon Express aims to extract resources available near the surface of the Moon, including valuable minerals and water for human life support and conversion to rocket fuel. With a family of innovative robotic exploration spacecraft, Moon Express plan regular flights to the Moon from 2020.

The first mission, Lunar Scout, will demonstrate the cost-effectiveness of entrepreneurial approaches to space exploration, carrying a diverse manifest of payloads including the International Lunar Observatory 'MoonLight' from the IFN National Laboratories of Frascati and the University of Maryland, and a Celestis memorial flight. The second mission, Lunar Outpost, will enable the first commercial presence and exploration of the lunar South Pole. The poles of the Moon have concentrations of water and other valuable resources, as well as 'peaks of eternal light' where nearly continuous sunshine and direct communication with Earth are possible. The primary goals of this mission are to set up the first lunar research outpost, prospect for water and useful minerals, and accommodate a variety of research instruments for our expedition partners. The third mission, Harvest Moon, expected to take place by 2020, includes the first commercial sample return mission, which also begins the business phase of lunar resource prospecting.

In recent news, October 2018 saw Moon Express sign a Memorandum of Understanding (MoU) with the Canadian Space Agency (CSA) to explore options for collaboration. Under the agreement, the CSA and Moon Express will explore the possibilities of using the Moon Express lunar orbiter and lander systems for potential CSA payloads and will promote possibilities for collaboration between Moon Express and the Canadian space industry and academia.

Asteroid Mining Corporation (AMC) is one of the newest companies in deep space mining, having been founded in the UK in 2016 in order to 'advance the march of human progress and civilisation by bringing the world the Third Industrial Revolution: Moving as many polluting industries into space and out of Earth's fragile biosphere as possible so that the Earth can become the garden of the Solar System.' The company aims to build the infrastructure to support a space-based population and space-based economy, which will of course require the extraction of deep space resources.

AMC has three objectives in its short-term plan. The first it to conduct robotic operations in space via the development of a small satellite dubbed ASP1, a 6U spectroscope space telescope, which will gather spectrographic data on target asteroids that will be

made commercially-available. Indeed, in July 2018, it emerged that AMC is seeking UK£2.3 million to build a satellite capable of identifying platinum-group metal deposits on near-Earth asteroids, namely ASP1. The second objective is the development of an additive manufacturing system for printing metals in space, which will enable the production of structural and component elements for orbital installations. The third is the production of a probe that can intercept an asteroid and excavate a volume of material.

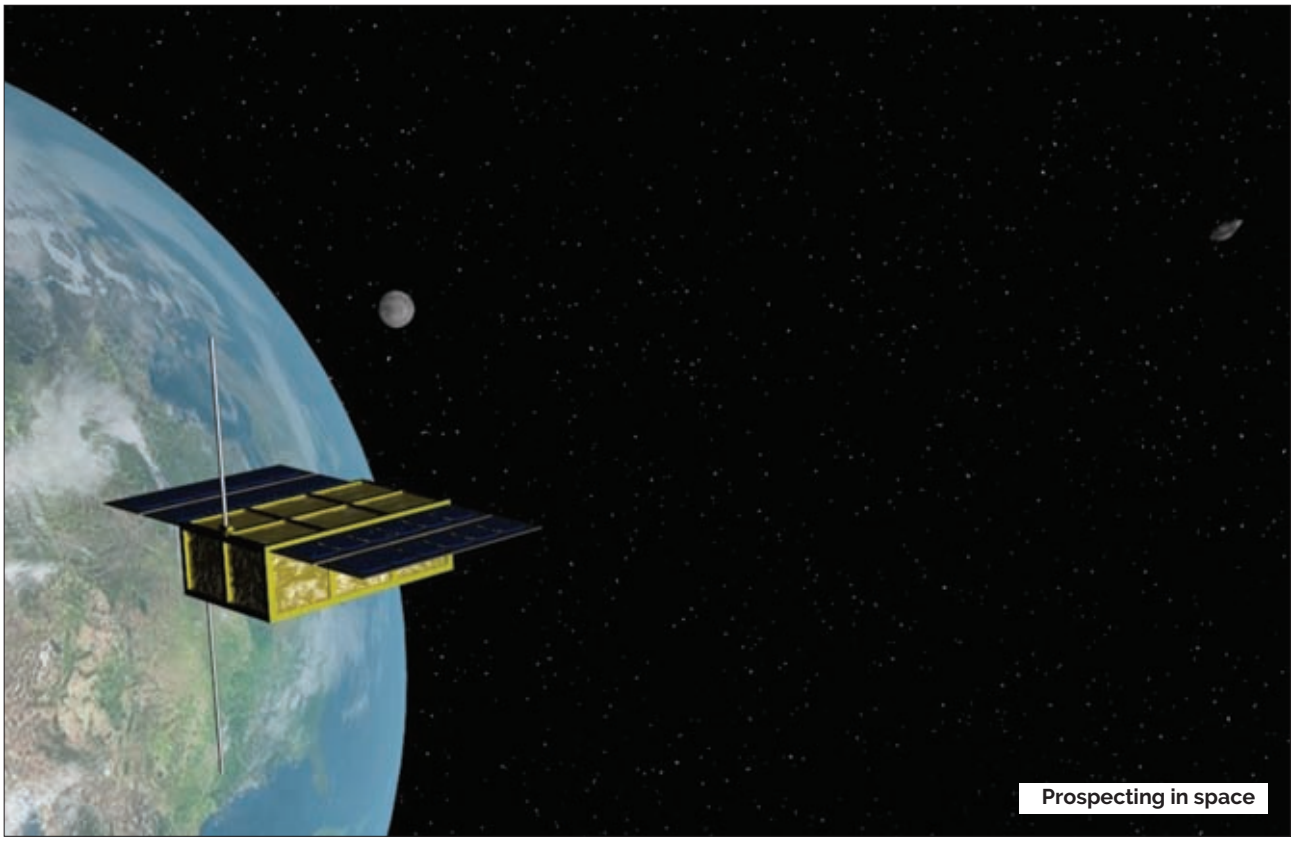
TransAstra Corporation's vision is somewhat similar to AMC's, namely for humanity to 'become a spacefaring species homesteading the solar system.' The company would see thousands of asteroids transformed into refuelling stations for NASA (the NASA Emerging Space Office awarded the company a grant to study the economic impact of asteroid in-situ resource utilisation – ISRU) and commercial spacecraft and plans to lead the work in supplying services for asteroid mining, space solar power, space tourism and space-based manufacturing. While little information is available on its own website, TransAstra's Chief Technology Officer Joel Sercel produced a directorate published by NASA spelling out plans for Optical Mining of asteroids, which will reportedly provide affordable mission consumables and radiation shielding. In Optical Mining, excavating and processing asteroid materials is accomplished by highly-concentrated sunlight, which TransAstra has shown can be used to drill holes, excavate, disrupt, and shape an asteroid while the asteroid is enclosed in a containment bag.

During its Phase 1 work, the company demonstrated Optical Mining in the laboratory and performed mission and systems analysis of the application of Optical Mining to human exploration missions. Mission analysis showed that the most accessible Near-Earth Objects (NEOs) can be used to provide mission consumables for human exploration in deep space with the potential of saving up to US$10 billion per year. Phase 1 technical work included a full scale 8kW Optical Mining demonstration using a high-fidelity CI-type asteroid simulant in vacuum using sunlight from a 10m diameter solar concentrator without mechanical contact or downforce.

Moving onto Phase 2, TransAstra will complete mission and system analysis of the application of Optical Mining to an exciting program of human exploration and we will mature the technology of Optical Mining to the point at which NASA can baseline this approach for an affordable program of human exploration. Mission studies will address the production via Optical Mining missions to extract and retrieve resources, consumable processing, storage, and application of consumables to human exploration mission in cislunar, NEO and Martian space. The mission studies will be tightly coupled with laboratory work, which will include the development and integration of a 30kW Optical Mining test apparatus and integration with a high-quality vacuum chamber for a test program involving Optical Mining.

The next gold rush?

Deep space mining is an expensive game, and it certainly won't be the free-for-all 19th Century gold rush we experienced in Australia, New Zealand, South Africa, Canada and the USA. But that doesn't mean there aren't big bucks to be made, for those bold enough to reach. There's a lot still to be achieved, particularly on the technological side, but there's a lot of opportunity too. Noted experts like Neil deGrasse Tyson certainly seem to think so: "The first trillionaire there will ever be is the person who exploits the natural resources on asteroids," said Tyson. "There's this vast universe of limitless energy and limitless resources. I look at wars fought over access to resources. That could be a thing of the past, once space becomes our backyard."



Prospecting in space