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## Planetary Resources Inc., Property Rights, and the Regulation of the Space Economy

Planetary Resources, Inc. (PRI) had a bold, some said crazy vision: to mine asteroids.<sup>a</sup> As cofounder Peter Diamandis explained, "Since my childhood, I've wanted to do one thing, be an asteroid miner."<sup>1</sup> Diamandis and his cofounder Eric Anderson, both veteran engineers and storied entrepreneurs in the New Space sector, believed that the right mix of technology, capital, and passion could tap the nearly infinite resources of space, facilitating the growth of a space-based economy. "My childhood dreams were focused on being part of the effort to make humanity a multiplanetary species," Diamandis recalled. "Ultimately it's what we do. We have the exploration gene."<sup>2</sup>

One might have assumed that developing the right technology would be the greatest challenge facing PRI. But even if the fledgling company could develop and deploy the sophisticated imaging, prospecting, and communication capabilities required for mining asteroids, two additional obstacles meant success was not guaranteed.

First, uncertainty remained over whether, and how, property rights to resources mined in space would be enforced. In particular, language in the internationally recognized Outer Space Treaty (OST) left the types of commercial activities permissible in space open to interpretation. In the New Space industry, hopes were high that Title IV of the U.S. Commercial Space Launch Competitiveness Act (CSLCA), lobbied for by PRI and signed into law in 2015, had resolved this uncertainty by explicitly granting U.S. companies the right to sell resources they extracted in space. But signs of disagreement with the CSLCA's interpretation of the OST, especially at the United Nations, put those hopes in question and highlighted the lack of a global authority for settling property rights disputes.

PRI's leadership's challenge was to anticipate, and perhaps shape, how this uncertainty would be resolved. After all, these property rights debates were all had in the abstract, but they would take on new urgency once a company such as PRI started to succeed in acquiring resources from space. PRI needed a strategy that would not only be robust to the eventual resolution of that debate but also take advantage of what it believed would happen.

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<sup>a</sup> See Anette Mikes and Amram Migdal, "Planetary Resources, Inc. (A)," HBS 114-087 for an in-depth case study of PRI's strategic decision-making, talent recruitment, and workflow management processes.

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Making that balancing act more difficult was a second factor: a complex and underfunded U.S. regulatory infrastructure that threatened to slow PRI's progress and escalate costs. Two independent agencies of the U.S. government were relevant for the company's core operations. These agencies faced tight budgets and constrained staffing, slowing their work, and there was little coordination on policy between them. "You have to have a process, you have to have someone who's designated as the lead of the process, and you have to have the funding to make sure the people are there to actually produce the licenses and do the reviews that we need," said Peter Marquez, PRI's VP of Global Engagement and former Director of Space Policy under Presidents Bush and Obama. Moreover, a multi-agency review process for regulatory decisions involved numerous indirectly related agencies and further complicated the regulatory environment. "People are still trying to figure out which horse is the lead horse," Marquez continued.

One way for PRI to circumvent, rather than overcome, these obstacles was to look for a national partner other than the United States. In early 2016, the tiny country of Luxembourg, which lacked its own spacefaring capabilities but was home to one of the world's largest commercial satellite companies, announced an initiative to become the hub of space mining. Named spaceresources.lu, the initiative would offer companies like PRI and Deep Space Industries (DSI), its closest competitor, a friendly regulatory environment and financial incentives in order to support and nurture their development. DSI moved quickly to establish a subsidiary in the European country and embrace further participation in spaceresources.lu. Was it time for PRI to look abroad as well?

## Planetary Resources, Inc.

Before co-founding PRI, Peter Diamandis and Eric Anderson had already made names for themselves as pioneers in so-called New Space, a movement of commercial space companies seeking to redefine the relationship between the public and private sides of the space sector as well as assert a greater role for the private sector in the use and development of space more generally.<sup>b</sup> "We have a long track record of making large-scale space ventures real,"<sup>3</sup> said Diamandis.

Most notably, in 1996 Diamandis developed the Ansari X Prize, a competition awarding \$10 million from private donors to the first non-governmental organization to reliably launch a manned vehicle past the 100km Karman Line, the internationally-accepted edge of space. In 2004 Scaled Composites, financed by Microsoft co-founder Paul Allen and led by engineer Burt Rutan, was awarded the prize after the second historic landing of its SpaceShipOne spaceplane.

Around the same time, Anderson founded the company Space Adventures to "open the space frontier to private citizens" not just specially trained government astronauts.<sup>4</sup> Space Adventures sent the first private space tourist, American engineer and entrepreneur Dennis Tito, to the International Space Station (ISS) in 2001, followed by six other travelers over the next decade.

Along with a surge of government funding for commercial space, these early successes set the stage for the rise of New Space. Between 2000 and 2011, the U.S. government granted \$5.9 billion through a series of public-private-partnerships to New Space companies to facilitate lower cost access to space through its Other Transaction Authority (OTA). The National and Commercial Space Programs Act of 2010 declared that "the general welfare of the United States requires that the Administration seek and encourage, to the maximum extent possible, the fullest commercial use of space."<sup>5</sup> In general, the U.S. government was acting as the anchor tenant for a variety of private

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<sup>b</sup> See "Blue Origin, NASA, and New Space (A)," HBS 716-012 for a discussion of private space activities and the public-private-partnerships between NASA and New Space companies from 2000 to 2011.

companies' space capabilities, hoping to help them overcome uncertainty over prospective demand and build the markets that would make them self-sustaining.

During this time, New Space startups pursued a range of commercial space concepts, including bold visions of space tourism, colonization, and extraction of lunar or asteroid resources (see **Exhibit 1** for a sample of private New Space companies from NASA's 2014 Emerging Space report).

### *Founding and initial strategy*

After its founding, interest in PRI grew quickly, with headline-generating investments from tech billionaires such as Google founder and CEO Larry Page, Google chairman and former CEO Eric Schmidt, and Virgin Group founder Richard Branson. The firm's focus on private capital reflected Diamandis's belief that privately funded companies were the future of the space sector. In an interview in 2014, he explained, "The Bush administration was supposed to start a massive effort to go back to the Moon and on to Mars. It fizzled. That's when I got it: This was never going to happen. Any time a new Congress came in, it would cut NASA's budget. Commercial industry was the only way to generate long-term funding for bold, risky projects."<sup>6</sup>

Despite their grand visions, PRI's leadership recognized that developing a sustainable business and attracting talented employees would require their aspirations to come down to Earth, at least for the short term. "It's hard for a company in this industry to have a long term goal without an immediate revenue generation model," said Marquez.

The company set its sights on the market for Earth observation. Already at \$1.6 billion in 2014, with expected growth of 80% over the next decade,<sup>7,8</sup> the Earth observation industry was concentrated in the United States, with fewer than 10 imaging companies producing commercially available data, and the U.S. government accounting for 60% of total spending.

Providing observation services could serve as an initial site for the testing, proof, and application of many of the technologies PRI would develop for asteroid surveying, buying time for future space resource-based markets to emerge and regulation to catch up.<sup>9</sup> The company planned to test its software control systems and avionics through missions to the ISS, as well as to develop its sensors and imaging satellite capabilities. In 2013, PRI developed its Arkyd 100 satellite, which cost \$1 million to build and \$1 million to launch, weighed 44 pounds, and had a 10- to 15-meter resolution. The company hoped its technology would disrupt the existing market for small-range imaging satellites, which could both cost and weigh over ten times as much and offered similar image quality. In 2015, PRI launched the demonstration Arkyd 3R satellite from the ISS to test the avionics electrical controls, and planned two Arkyd 6 satellite launches in 2017 to demonstrate sensor technology.

### *Long-term strategy*

PRI's long-term vision was to establish a new paradigm for resource utilization to bring the Solar System within humanity's economic sphere of influence.<sup>10</sup> With 60 million asteroids in the Solar System, about 15,000 of which were near-earth asteroids (NEAs) reasonably within reach with current spacefaring technologies, and about 2,500 NEAs energetically closer than the Moon, the potential seemed enormous. What markets those resources could serve profitably, however, was as yet unclear.

**Resource use on Earth** One option was to mine asteroids for resources that could be used on Earth. PRI estimated that a single asteroid could be worth trillions of dollars. Platinum—a rare element on Earth used in electronics manufacturing, medical devices, renewable energy technologies,

catalytic converters, and infant fuel cell technologies—and other rare Earth metals were expected to be abundant on individual asteroids. The company estimated, from initial Earth-based observations, that one of the most massive bodies in the Solar System (which flew by Earth in July 2015) could contain up to 90 million metric tons of platinum, and (depending on the homogeneity of its composition) could be worth between \$300 billion and \$5.4 trillion.<sup>11</sup>

Asterank, a scientific and economic online database that catalogued the composition, accessibility, value, and estimated profit of over 600,000 asteroids from public government and scientific sources, estimated that over 700 asteroids in the Solar System's Asteroid Belt were each worth over \$100 trillion in water or precious metals (see **Exhibit 2**).<sup>12</sup>

Complicating this strategy, experts argued that resources in the Main Belt were not economically recoverable. "Ore-bearing, i.e. potentially profitable, asteroids are rare," Harvard-Smithsonian astrophysicist Martin Elvis explained, "One major factor is the limited nature of our existing and near-term rocketry,"<sup>13</sup> which kept the cost of transporting resources high and limited the set of asteroids that could feasibly be mined. The immense velocity requirements of rockets to reach asteroids, combined with the massive instrumentation and mining equipment essential for such missions "rules out Main Belt asteroids, for now."<sup>14</sup>

More promising were NEAs. Using data collected by Earth-based radar and optical and infrared telescopes, PRI identified eight target NEAs with sufficiently low delta-v values (representative of the forces needed to reach an object in space from Earth) for future space-based imaging and prospecting missions. (See **Exhibits 2** and **3** for a summary table of target asteroids and an illustration of PRI's target asteroid orbits.) While these NEAs would not likely return resources worth trillions, as Main Belt asteroids might, NEAs were typically much more accessible, with delta-v requirements of less than 5 km/s.<sup>c</sup> In fact, highly valuable asteroids passed exceptionally close to Earth. In 2013, an asteroid known as 2012 DA14, carrying an estimated \$130 billion in precious metals, passed Earth at a historically close altitude of 17,200 miles (closer than satellites in geostationary orbit, which traveled at 25,000 miles above Earth's surface).<sup>15</sup>

If a resource-rich asteroid were successfully mined, the surge in supply on Earth had the potential to drive prices down sharply. Elvis warned, "*Ore-bearing* is a technology dependent term...It is also economics dependent, as a drop in price can render material non-ore-bearing."<sup>16</sup> But PRI shrugged off concerns about causing a sharp price drop with a huge boost in supply: "I would be overjoyed as a company if we brought back so much platinum that the price fell by a factor of 20 or 50," Anderson said.<sup>17</sup>

Such a significant drop in a resource's price as a result of a supply shock, PRI argued, would not cripple its market, but rather would prompt its demand to skyrocket. Marquez pointed to an analogous example: aluminum. In the 19<sup>th</sup> century, the price of aluminum exceeded that of both gold and silver. "Aluminum was *the* scarcest material and now think of all the uses for it. There are plenty of uses for platinum group metals that just aren't utilized because of its scarcity. Whether it's for medical devices, catalytic converters, or anything else, you drive up the ubiquity of its uses with an increased supply."

**In Situ Resource Utilization** A nonexistent but potentially larger market for resources extracted in space would be in space itself, through so-called In Situ Resource Utilization, or ISRU. "In

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<sup>c</sup> For comparison, the delta-v required to reach the Moon from Earth (roughly 0.01% of the distance from the Earth to the Main Asteroid Belt) was 16 km/s.

my view," commented John Brophy, NASA Johnson Propulsion Laboratory engineer and co-leader of a Keck Institute for Space Studies report on the feasibility of asteroid retrieval, "it's questionable how the economics of asteroid-retrieval works if you're going to bring it to the ground. It makes more sense if you're going to use the material in space."<sup>18</sup> With dreams of space tourism, lunar and Martian colonization, microgravity manufacturing and scientific research, and interplanetary travel, utilization of space resources would likely become necessary, and potentially more profitable in space than on Earth.

For example, water harvested from the Moon or asteroids could be electrolyzed into its constituent parts, hydrogen and oxygen, the two components of traditional rocket propellant. If fuel could be produced and stored in Low Earth Orbit (LEO) fuel depots, the cost of interplanetary travel could come down significantly, as a launch vehicle's fuel requirements typically comprised 30 percent of traditional total launch costs.<sup>19</sup> The Space Shuttle, for example, consumed roughly 600 metric tons<sup>d</sup> of propellant on each mission, approximately the same as did the Delta IV, the modern heavy-lift rocket manufactured by United Launch Alliance.<sup>20</sup> Despite the significant reduction in cost to launch payloads to LEO from \$15 million per metric ton on Shuttle at its retirement in 2011, to an expected \$2.7 million per metric ton in 2018 by the SpaceX Falcon 9 commercial rocket launcher,<sup>21</sup> overcoming gravitational forces and atmospheric drag on Earth would remain more costly than launching from the surface of the Moon or asteroids, which incurred a fraction of these losses.

Reachable NEAs also appeared to contain substantial water resources. The 45-meter asteroid 2012 DA14 was thought to be carrying not only precious metals, but 6,500 metric tons<sup>e</sup> of recoverable water,<sup>22</sup> and preliminary estimations projected that one of PRI's target asteroids, Ryugu, contained 9,500 metric tons. Anderson commented, "One 75-meter carbonaceous chondrite asteroid contains enough hydrogen and oxygen to have launched all 135 space shuttle mission."<sup>23</sup>

Some analysts argued that space "gas stations" already had a small but growing market from government space agencies on their way to the Moon, asteroids, and other parts of the Solar System. In 2011, NASA had launched a project called Cryogenic Propellant Storage Transfer to study how to handle and store ultra-low temperature liquids in space. But the demand for in-space fuel would have to grow to meet the potential supply PRI projected, as current in-space fuel consumption to position and reposition spacecraft had only reached 250 metric tons annually.

Orbiting fuel depots also could complement heavy-lift launch technologies like NASA's Space Launch System (SLS), a program slated to cost \$9 billion by its proposed first launch in 2017.<sup>24</sup> According to Michael Gazarik, NASA's space technology program director, "To explore deep space we need a heavy-lift vehicle—SLS...We [also] need a deep-space vehicle, and we know the vehicle's going to need propellant."<sup>25</sup>

Most optimistic was the view that ISRU would provide the essential ingredients for a self-supporting space economy. For example, water could benefit future space voyagers, be they colonists, tourists, or biotechnology researchers, by acting as a shield from harmful solar radiation in environments that lacked the protective atmosphere and magnetic field surrounding Earth. And the quantities required for shielding would be large, generating substantial demand for what PRI could supply. Approximating the demand for radiation shielding for a deep space orbital human inhabitation, Elvis speculated, "A naïve calculation making the mass of shielding equal to the mass of

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<sup>d</sup> Metric ton is a unit of mass. Rocket launch costs are typically driven by total launched mass, including payload and on-board fuel.

<sup>e</sup> NASA estimated the mass of DA14 to be 130,000 metric tons with 5% recoverable water assumed.

Earth's atmosphere at sea level suggests on the order of 10 tons of shielding per square meter. Hence thousands of tons of shielding would be needed [for each space station]...Water makes good radiation shielding and this could become a usefully large market for resources from space."<sup>26</sup> Of course, who would pay for these radiation shields – and how much – remained unclear.

But critics cautioned against investing in resource mining before space-based markets emerged. David Portee, a former space historian at NASA's Johnson Space Center, argued, "Right now it would be like a big oil tanker dropping anchor off the coast of medieval England. The medieval English might identify the oil as a useful commodity, but wouldn't be able [to] use enough to profit the tanker crew. Heck, they wouldn't know how to get it off the tanker, except in wooden pails and rowboats."<sup>27</sup>

### *Policy uncertainty*

These technological and economic challenges were not the only concerns voiced by potential investors in PRI, however. "Early investors wanted to draw down the risk on the policy side," Marquez explained. If PRI were to secure an asteroid worth even a fraction of its estimates, would the company be allowed to claim such an enormous bounty? Easing potential investors' political and legal worries would remain a constant challenge for the company.

In particular, PRI saw the U.S. government's granting of property rights in space to domestic companies and streamlining of its regulatory infrastructure as critical first steps toward the company realizing its mission. "Companies were looking to the government, begging them to regulate," said Marquez. (See **Appendix A** for effects of regulation on structuring the airline industry.)

## **Property rights in space**

In 2010, when Diamandis and Anderson founded Arkyd Astronautics, the company they would soon rename PRI, the idea of asteroid mining remained a distant prospect. But international policymakers had been anticipating that future, and thinking about how to regulate it, for decades.

### *Outer Space Treaty, 1967*

At the dawn of the Space Age, international policymakers sought to guarantee that space was used peacefully and responsibly. In 1957 the Soviet Union launched Sputnik, the world's first artificial satellite, and the United States responded with the remarkable Apollo program, eventually delivering a dramatic manned lunar landing in 1969. While U.S. and Soviet space capabilities advanced and geopolitical tensions escalated, outer space threatened to become a new-aged battlefield. In response, policymakers sought an agreement that would ban military activity in space. The result was the 1967 Outer Space Treaty (OST), in which signatories agreed to the statement: "The moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes."

The OST intentionally established no regulatory framework for governing the economic development of space. Instead, it included the following passage, which would become central to debates over property rights and PRI's plans: "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."<sup>28</sup>

Analysts noted that the authors of the OST also avoided using precise legal concepts to describe the status of space. The treaty asserted that the “exploration and use of outer space...shall be the province of all mankind,” but that final phrase had no established meaning in international law. Other phrases, such as *res nullius* (a thing that belongs to no state but could), *res communis* (a thing that belongs to all in common), and *res extra commercium* (a thing that cannot be owned) each had more precise legal meanings but were, apparently, not what the treaty drafters had in mind for space. As Henry Hertzfeld (a space policy professor and former NASA analyst) and researchers at the Secure World Foundation noted, “none of [these terms] provide an adequate framework for the future handling of space resources [or] space exploration.”<sup>29</sup> This semantic confusion left open the question of whether certain activities – specifically space resource extraction – were appropriate under the treaty.<sup>30</sup>

Importantly, the OST granted non-governmental entities the right to operate in space, opening the door for commercial capabilities such as remote sensing, telecommunications, and launch operations. In their infancy at the time of the treaty, these areas would support thriving industries in the decades that followed. To provide oversight for private sector actors, the OST required that each of the 104 signatory governments, including the United States, the Soviet Union, and China, be responsible for the actions of their non-governmental entities' space activities.<sup>f</sup>

### *Moon Treaty, 1979*

A handful of countries sought clearer restrictions on economic activities in space than those provided in the OST, especially with regard to the Earth's Moon. In 1979 they drafted the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (the Moon Treaty), defining “the moon and its natural resources as the common heritage of mankind,” intending to limit the scope of private activities. But the Moon Treaty failed to garner the support of key actors in space, and only a handful of non-spacefaring nations ratified the agreement.<sup>31</sup>

For decades, the international regime on property rights in space saw little movement. Then, in a bold—some said brazen—move, the U.S. government changed the game. (Refer to **Appendix B** for summary of related treaties on international property rights on Earth.)

### *The Commercial Space Launch Competitiveness Act*

The U.S. Commercial Space Launch Competitiveness Act (CSLCA), passed into law in November 2015, Title IV of which granted American private companies property rights in space. The law promoted “the right of United States citizens to engage in commercial exploration for and commercial recovery of space resources free from harmful interference, in accordance with the international obligations of the United States and subject to authorization and continuing supervision by the Federal Government.” The CSLCA asserted that U.S. citizens intending to extract space resources were “entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell the asteroid resources or space resource obtained in accordance with applicable law.”<sup>32</sup>

**PRI's role** “We haven't been able to just let the regulation come about on its own. It's been a crucial part of our company activities,” said PRI's Marquez. In 2013, the company hired seasoned

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<sup>f</sup> See “Astroscale, Space Debris, and Earth's Orbital Commons,” HBS 716-037 for a discussion of private and public responsibilities for man-made space objects.

space lobbying firm K&L Gates (with former clients SpaceX and the Commercial Spaceflight Federation) to represent the space mining industry and push for the necessary legislation.

“There was a discussion among the leadership at PRI, our legal advisors, and lobbyists, as to what would be the most effective path forward,” said Marquez. He continued:

We looked at the whole gambit of options, weighing things from modifying the existing [Outer Space] Treaty, to an executive order, to creating new legislation, to doing nothing and allowing case law to prove itself out. You can immediately take some things off the table. Modifying the existing Treaty has major challenges with the least certain outcome. On the other extreme of doing nothing, we believed that was just maintaining status quo and we were trying to do more than the status quo to improve investor confidence. They want to know that if they invest, we will return a profit.

The PRI team concluded that the legislative path, while difficult, would be the best choice and drafted a 6-page bill to bring to members of the U.S. Senate and House of Representatives for revision and early support. They in turn brought the draft bill to members of the Executive branch (Departments of Defense, State, Commerce, and Transportation) whose support would be critical in the bill’s passage through Congress and subsequent authorization by the President. “We spent two years socializing it, refining it, getting House and Senate to buy-in to the document so that it came out the other end a one-page bill that was attached to the bigger Space Act bill, which became Title IV of the final law,” said Marquez. He continued:

There were three sections in the original draft that were really important to us. One was the recognition of rights: if you go to obtain a resource, it’s legally yours. The other two sections had to do with the legal process if there was a dispute. There was one section that said, in accordance with the OST, all parties have the right to operate free of harmful interference. And if you are being harmfully interfered with, you have a right to go to court. The next section said that, when it’s brought before a judge, the judge should rule according to “reasonableness” of each party’s claim, which is how any court is judged, and – the contentious notion – called “first in time”: the first in time to be conducting an activity related to the recovery of resources in space.

Despite government support, critics of the draft bill threatened to derail its progress. They argued that the “first in time” clause benefited the first mover of any activity and could allow a company engaging in remote observations to claim that it was the first to begin resource recovery activities on all observable asteroids and prevent a competitor from initiating its own extraction processes.

Sagi Kfir, General Counsel at California-based Deep Space Industries (DSI), PRI’s closest competitor, explained: “We’re grateful to PRI for getting the process started but their original draft had a number of problems.” According to Kfir, the PRI draft bill was not technology agnostic, and in fact favored PRI’s hyperspectral analysis process. “Based on the ‘first in time’ principle,” Kfir continued, “PRI could put their technology in LEO, point it to asteroids in all directions, and if we at DSI, after investing heavily and travelling months to actually land on an asteroid but kicked up some dust in the process, PRI could claim in federal court to have been first to be engaging in recovery based on their hyperspectral prospecting from LEO, and the judge would be bound to rule in their favor based on the ‘first in time’ language in the legislation.”<sup>33</sup>

Marquez responded to such contentions: “You can’t claim asteroids. We all know you can’t claim asteroids, and just because I observe something remotely, doesn’t mean I’ll claim that I’m actually doing anything in the recovery of resources.” At the same time, by creating an adjudicatory

framework whereby judges would rule in favor of “reasonable non-interference”, the draft bill protected companies from competitors that solely intended to “lick the cookie so no one else could eat it anymore,” as Marquez put it. That is, a company legitimately collecting scientific data remotely for the recovery of resources could prove its recovery objectives and would have a valid claim in court against a competitor that deliberately obstructed such activities by landing on the asteroid and kicking up dust or simply firing a satellite into it – technically the first to be physically on the asteroid, but not engaging in sincere recovery efforts. “That’s why both the ‘reasonableness’ argument in combination with the line that says ‘doing activity related to resource extraction’ was so important,” Marquez explained.

In the end, both the “first in time” and “reasonableness” phrases were removed from the final version of the bill, which passed in late 2015. “It took two years,” said Marquez, “but I think the right product came out because all these people from multiple branches of the government were supportive and in the end, nobody voted against it. It was passed by unanimous consent – 535 ‘Yes’ votes [all 100 in the Senate and 435 in the House of Representatives].”

**International reaction** Never before had legislation granted private entities such privileges in space, particularly for commercial extraction and use of space resources, and whether the United States could grant such rights to the private sector would prove to be a point of contention.

Some nations welcomed the progressive steps taken by the United States. Referring to the existing international space treaties, the Italian delegate for the 2016 UN Committee on the Peaceful Uses of Outer Space (COPUOS) Space Law conference commented, “They are aging treaties...These treaties are aging due to the fact that since they were adopted, situations [in the international space sector] have heavily changed...We would like to stress that we are confident that the U.S. will take into consideration their own international obligation...The [CSLCA] Act is full of references to their international obligations to the UN.”<sup>34</sup>

At the same time, international dissenters argued that the new legislation could not be reconciled with the United States’ obligations under the OST. The OST endorsed the exploration and use of space, but the CSLCA dramatically expanded that list of activities. To some countries, the CSLCA went too far.

Russia was particularly vocal in its opposition. In a working paper submitted for the 2016 COPUOS Space Law conference, the Russian Federation contended:

The United States vividly demonstrated a connection between diminishing the Committee [on the Peaceful Use of Outer Space]’s role and powers, on the one hand, and manifestations of total disrespect for international law and order, on the other, by adopting the commercial space launch competitiveness act...Trying to avoid ambiguity and wishing to endow its own actions with the appearance of legitimacy, the United States also proclaimed a new understanding of ‘national appropriation of outer space, including the Moon and other celestial bodies’ which, according to their reasoning, does not derogate from the pivotal obligations under the 1967 Outer Space Treaty...[T]he United States decided to resort to an argument, which had been mainly voiced by the academic community before, that Article II of the 1967 Outer Space Treaty, that prohibits the above national appropriation, does not affect the resources since it is not established *expressis verbis*. Something is entirely wrong with such current manifestations.<sup>35</sup>

The U.S. government countered that it was in fact adhering to the OST. The CSLCA read: “the United States does not thereby assert sovereignty or sovereign or exclusive rights or jurisdiction over,

or the ownership of, any celestial body.<sup>36</sup> It argued that property rights were to be awarded under the CSLCA as a result of physical extraction of the resources and not for territorial claims.

But critics saw these arguments as disingenuous attempts to preempt inevitable opposition. "In the reality of outer space, domestic legislation, however well-meaning, will often provide us with a poor substitute that falls short of achieving what can only be realized by means of a multilateral instrument that can take into account the interests of the international community," noted a statement from Brazil. It continued:

We share the understanding of other nations who see inconsistencies between national legislations that allow the economic exploitation of celestial bodies and the principles set forth in the UN treaties on Outer Space. Unilateral legal initiatives applicable to a field where multilateral interests must necessarily take priority over national ones are an unsuitable, and indeed unwelcome, development in the field of space law, as they are highly likely to lead to situations that might give rise to conflicts of interest, with all the unwanted consequences that may result from such conflicts.<sup>37</sup>

Not only did individual nations voice concerns over the implications of the 2015 CSLCA, but in his departing address as Chairman of COPUOS, Azzedine Oussedik of Algeria warned of its potential consequences, particularly the disadvantage it would impose on signatories of the Moon Treaty, while allowing U.S. companies the ability to seize space resources for themselves: "I'm afraid it would be an unacceptable situation, moreover a catastrophic defeat for COPUOS, if the state parties to the Moon Agreement were busy establishing an international organizational regime, while in the meantime the commercial companies of the states not party to this [Moon] Agreement would freely exploit the natural resources of the celestial bodies."<sup>38</sup>

In particular, the U.S. CSLCA raised concerns for many developing nations that relied heavily on the export of resources to sustain their economies. Olavo Bittencourt Neto, Vice Chair of The Hague Space Resources Governance Working Group (a public and private consortium of space sector stakeholders), explained, "These nations that make up the 'global south'...will not be engaged in the extraction of resources in space in the early phases of exploration and exploitation. But they will suffer the consequences...It's important to take into consideration the fact that this kind of activity will produce shockwaves around the globe."<sup>39</sup>

The problem, Neto noted, was that the OST no longer sufficiently protected all nations' interests in space:

What we're seeing is a crisis of the international legal framework...The most important treaty, the OST, is pushing 50 years. It was first considered in the Cold War, a different era. Treaties are, in one way or another, pictures of the moment. They reflect the fears and concerns of states at that given period of time. In order for them to be kept useful, they need to be interpreted. And what we're seeing right now is that since we do not have any clear provision related to the exploitation, exploration, [and] mining of space resources, states are beginning to provide unilateral interpretation of those rules through municipal law and national legislation.<sup>40</sup>

Underneath critics' objections were both self-interest and the view that the OST was designed to protect the space environment and preserve space and its resources for future generations. "This is an activity that will have an effect everywhere," added Neto, "It's related to international territory - territory that's considered the province of all mankind."<sup>41</sup> But PRI believed its work mining asteroids could in fact have immediate benefits everywhere. "My response to critics that say we can't bring

back space resources because space is for the benefit of all mankind," said Marquez, "is that if we bring back a lot of platinum, guess who's benefiting? Whether it's for medical devices, catalytic converters, cancer treatments; you name it, we're bringing back material that helps all mankind. We just happen to make a profit. There's no evil in making a profit."

### *Theories of property rights and resource extraction*

The distinction made in the CSLCA – that resources could be extracted from space objects and claimed as property without an individual laying claims to the object itself – alluded to the writings of the prominent 17<sup>th</sup> century philosopher John Locke, whose writings also strongly influenced the early political leaders of the United States. Three components of Locke's view of property rights were especially relevant to the debate over resources in space.

First, Locke argued that in the absence of a sovereign government, property rights could come about from mixing one's labor with a natural resource. In his 1689 *Second Treatise on Government*, Locke wrote, "The labour of his body, and the work of his hands, we may say, are properly his. Whatsoever then he removes out of the state that nature hath provided, and left it in, he hath mixed his labour with, and joined to it something that is his own, and thereby makes it property."<sup>42</sup> Consistent with this idea, the CSLCA asserted that private space mining companies could, by putting forth their own efforts, claim the resources they extracted without staking claims to the ground from which they were obtained.

Second, Locke defended the claim of private property so long as it resulted in "enough and as good left in common... For he that leaves as much as another can make use of, does as good as take nothing at all." The American philosopher Robert Nozick named this qualification the Lockean Proviso in his 1974 book *Anarchy, State, and Utopia*, where he interpreted it as holding that appropriation was justifiable, even though it directly diminished the rights of others to a resource, if each individual was left at least as well off as in a world where all resources had remained unowned. This justification for asteroid mining was at the heart of the moral case for the CSLCA, in that supporters saw the potential for space to provide almost limitless resources for humanity. They feared that this potential would remain largely – perhaps entirely – untapped unless the private profit motive was allowed to spur investment and risk-taking.

Third, Locke's theory included precisely the idea of "first in time" championed by PRI. To Locke, property rights arose when an individual established a claim to a resource previously left unclaimed. By virtue of being first, the individual acquired rights of ownership over the property that the state was obligated to protect.

Though Locke's theory of property rights was widely celebrated and influential, other important thinkers disagreed and offered alternatives that aligned with the criticisms of the CSLCA. In particular, the 18<sup>th</sup> century philosopher David Hume believed that "Our property is nothing but those goods, whose constant possession is establish'd by the laws of society; that is, by the laws of justice."<sup>43</sup> To Hume, property rights were dependent upon a process of argument and deliberation leading to a social and legal equilibrium. Critics of the CSLCA thought that the United States had circumvented this process for property rights in space and, thus, had failed to consider other countries' just claims. More fervent disagreement with Locke could be found in the writings of the 18<sup>th</sup> century philosophers Immanuel Kant and Jean-Jacques Rousseau, who thought that social consensus (not just a contested compromise) had to be sought before property rights could be endorsed by the state. They, like the critics of the CSLCA, stressed that the expansion of property rights should be subject to addressing concerns about distributive justice and the rights of dispossessed people (or countries).

## U.S. regulatory hurdles and the promise of Luxembourg

If the CSLCA removed (at least temporarily) legal barriers to PRI's strategy, regulatory barriers and uncertainty remained. Bureaucratic confusion, red tape, and interagency review processes bogged down licensing, inspections, and approvals crucial to mission testing and technical demonstration.

Activities in space were subject to license and launch review between commercial, civil, export control, and defense and security offices in the U.S. government. Professor Hertzfeld wrote, "Since there is no set process at present for some types of activities in outer space such as mining, resource usage, private exploration, etc., the lead agency for those types of in-orbit activities is not clear."<sup>44</sup>

Not only were the appropriate review channels unclear, but the agencies which oversaw space-related activities were scattered across the government. The Office of Space Commerce was tasked with the mission to foster economic growth in the space industry, including in the market for imaging services that PRI planned to enter. But it was housed within the Department of Commerce under the National Oceanic and Atmospheric Administration (NOAA), an agency primarily concerned with weather forecasts, fishery management, and coastal restoration. Meanwhile, the Office of Commercial Space Transportation (AST) was responsible for the licensing of commercial launches such as those upon which PRI would rely, but it was housed within the Federal Aviation Administration (FAA) of the Department of Transportation.

That organizational problem was exacerbated by the inadequate resources allocated to the managing agencies. The Office of Space Commerce had just two full-time analyst staff members, one responsible for the approval of remote sensing satellite applications, and the other managing all GPS services. With a modest budget of \$600,000, just ten percent of NOAA's annual appropriated funds, the Office of Space Commerce was already stretched thin.<sup>45</sup> And demand for its services was rising: the agency had seen an upswing in remote sensing license applications, issuing 13 licenses between 2014 and 2015 alone, relative to a total of 48 in the previous two decades.<sup>46</sup>

Moreover, for operating and launch application approvals, NOAA and the FAA each consulted with the U.S. Departments of Defense, State, and Interior. "U.S. regulatory regime problems have gotten bad in the remote sensing industry, a multi-billion dollar a year industry," said Marquez. The review and licensing process for infrared Earth imagery capabilities, which had never before been used in a commercial capacity - and that PRI aimed to develop, deploy, and test for later application in deep space - took six months for NOAA to process. "It's a matter of authority too," Marquez continued, "At the interagency level, the Department of Transportation is the little brother. The big dogs are the State Department, Department of Defense, the Intelligence community, and then everybody else. Having some oomph behind our requests would help."

One option some had considered to help expedite the process was through default license approvals. "Ideally, we'd want to just submit our plans and be able to execute them immediately," Marquez explained. "Since we have a lot of resources and investments riding on them, we can't slow down the train just because the government wasn't able to respond to our request before the approval deadline. There's a timeline, a fuse associated with the application package. And if you don't get it looked at and signed off on, the fuse is going to run out whether or not it's been approved."

The problem, however, was that historically, launch, reentry, and Earth observation activities were closely tied to safety and national security concerns and a default approval process was out of the question. "It's a residual left over from when the belief in the Pentagon and Intelligence

community was that if you were looking at Earth, you were going to be able to see all kinds of secrets and threaten national security. So the default was 'No', and you had to prove that you weren't a threat," said Marquez. "I completely agree with the interagency process," he continued. "As complicated as it is, you could never possibly imagine what *could* be an issue. It's important to make sure Defense or State are OK with what you're doing because there are risks you might not see. There's a reason for the interagency review process, it just needs to be responsive."

A second option was to establish a government agency dedicated to economic activities in space in support of a future thriving space-based economy. "We want to have one agency that supports us and understands the intricacies of what we're doing in our industry," said Kfir.<sup>47</sup>

Pressure for reform was mounting, and it generated some activity in Washington. Jim Bridenstine, a U.S. Representative from Oklahoma, announced the American Space Renaissance Act (ASRA), which included reform to remote sensing licensing: "Current law requires action to be taken on remote sensing license applications within 120 days. The Department of Commerce has in many cases missed this deadline, contributing to uncertainty, and delaying capabilities critical to our economy and national security."<sup>48</sup> Further, "the process by which license decisions are made is often unknown. When license applications are denied, justifications are often not given. This process needs to be transparent...When a license is approved, remote sensing companies make a business case and sign contracts."<sup>49</sup>

Though Bridenstine acknowledged that his proposal was unlikely to pass intact, ASRA echoed the concerns expressed by Marquez and Kfir. It read, in part: "The Department of Commerce has several entities within it related to space...These offices have small budgets, small staffs, and are buried deep within the bureaucracy."<sup>50</sup> And, "Currently, AST does not have the resources to efficiently or effectively carry out its duties, and will only be further stretched as commercial space activities expand."<sup>51</sup> To help alleviate this congestion, ASRA called for establishing a new position, the Associate Administrator of AST, and an improved metric to measure AST workload and encourage adequate budgetary appropriations.

In fact, the regulatory agencies in Washington wanted to be responsive to these concerns. As George Nield, Associate Administrator of the FAA for Commercial Space Transportation, said in 2016: "The State Department has recently acknowledged our current regulatory framework really wasn't designed to handle those kinds of non-traditional space operations given our statutory mission to encourage, facilitate, and promote commercial space transportation." The FAA expressed willingness to take on the responsibility of overseeing commercial activities that were not otherwise regulated by the Federal Communications Commission and suggested issuing formal mission licenses or authorizations specific for commercial activities. "Should the White House and Congress decide that that would be appropriate, the goal would be to enable those new, non-traditional commercial operations in space without creating a huge regulatory burden that would make U.S. companies less competitive," Nield continued. "We think this could be done quite easily... [and] would remove the regulatory uncertainty that several of the forward-looking and entrepreneurial companies are currently facing while still ensuring that we are compliant with our international treaty obligations."<sup>52</sup>

But in the absence of such support from the U.S. government, companies would likely consider other options. Nield noted this concern, adding that policymakers would have to ensure regulations did not establish unanticipated hurdles that, "in the worst case would drive [U.S. companies] offshore in search of a more business-friendly regulatory environment."<sup>53</sup>

### *Luxembourg's charm*

One opportunity for American space mining firms wishing to avoid domestic regulatory hurdles was to establish footholds overseas. Luxembourg, a core member of the European Union and Eurozone, with a population below 600,000 and GDP of \$60 billion in 2016,<sup>54</sup> aimed to establish itself as a global hub for space mining. And while the country lacked spacefaring capabilities itself, in February 2016 the Luxembourg government announced its *spaceresources.lu* initiative, looking to partner with private space mining companies and develop a legal and regulatory framework that would encourage and foster their presence in the country.

In its *spaceresources.lu* effort, Luxembourg would draw from its experience as home to SES, one of the largest commercial satellite fleet operators in the world, which had formed in 1985 with considerable help from the national government. "Similar to the private broadcasting and satellite communications visions formulated decades ago and successfully implemented," the government's website claimed, the push for resource extraction "may lead to a new chapter in the government's continued efforts to diversify the national economy."<sup>55</sup>

In fact, the government had recently announced its intention to propel the country into a "Third Industrial Revolution," with space mining as a crucial facilitator of that goal. "The idea is that space mining companies will develop technology in Luxembourg, employ people there, create IP there, and generate greater economic value there," said Marquez. The government also saw synergies between its robust financial sector and space mining initiatives in developing new financing mechanisms, funding projects, and establishing dedicated support programs.

*Spaceresources.lu* had full political backing from the country's Prime Minister, Xavier Bettel, and Deputy Prime Minister and Minister of the Economy, Etienne Schneider. "Our aim is to open access to a wealth of previously unexplored mineral resources on lifeless rocks hurling through space, without damaging natural habitats," said Schneider. "We will support the long-term economic development of new, innovative activities in the space and satellite industry as a key high-tech sector for Luxembourg."<sup>56</sup> Just four months after first publicizing *spaceresources.lu*, the government reaffirmed its commitment, announcing it would invest \$225 million to fund research, technology, and direct investment into private firms. "Luxembourg has the ability to become the Silicon Valley for space resources. That is our aim for the years to come," Schneider explained.<sup>57</sup>

The space resource extraction legislation that Bettel and Schneider envisioned would be the first of its kind in Europe and was expected to resemble the CSLCA. However, a key difference in Luxembourg's approach, Schneider noted, was that the "American Space Act only allows business to American companies, with at least a majority of American capital. The Luxembourg Space Act will be open to all investors, which will be located over here, in Luxembourg. That's a huge difference for investors - also to American companies or startups, which one day will have to get new capital...I don't know why the Americans limited themselves to American capital, but we will not."<sup>58</sup>

The legislation that Luxembourg would ultimately impose would not likely deviate far from the U.S. CSLCA. "The United States set up the rules to be the bare minimum to meet international treaty requirements. So there's really not much else Luxembourg could do that would lower the bar without being illegal," said Marquez. "It would hurt our ability to conduct business in the United States if people think we're just flying a flag of convenience in Luxembourg so we would want to make sure there is parity in the legal structures," he continued.

The *spaceresources.lu* initiative would be led by the Ministry of the Economy's Directorate of Space Affairs, Luxembourg's counterpart to the U.S. Department of Commerce's Office of Space

Commerce. Similar to the U.S. process, the Ministry of the Economy would cooperate with several other Ministries, including Foreign Affairs, Justice, and Media and Communications.

To avoid the delays that plagued U.S. interagency processes, however, an Inter-ministerial Task Force would handle coordination efforts. "Luxembourg is a small country where the people in the government know you," said Marquez. "There is a faster, more responsive regulatory process when leadership interacts directly with industry players and is well integrated in the process to move things forward...One advantage they offer is speed and their ethos focused on business and commercial activities. They don't have the same national security concerns as the United States - they're not worried about spy satellites they have up in space or classified missions being compromised because they just don't exist." Encouraged by the progress in Luxembourg, Chris Lewicki, President and CEO of PRI noted, "We commend the Government of Luxembourg in leading the world by establishing this new resource industry, thereby enabling the economic development of near-Earth asteroid resources."<sup>59</sup>

With support for space mining activities coming from its top leaders, and few layers of the government to sift through for approval of technology demonstration, Luxembourg drew immediate interest. DSI had jumped early, establishing a subsidiary branch in Luxembourg and, in May 2016, revealed its participation in spaceresources.lu with its inaugural mission, Prospector-X. DSI CEO Daniel Faber commented on the value of the experience that Luxembourg brought to the partnership: "[Luxembourg has] the largest company in the largest sector of the space industry already based here...They get it. It's in their psyche here that this is something you can make money off and this is something you can grow...Here we are encouraged to be a commercial company and go after a profit maybe."<sup>60</sup>

Luxembourg recruited former European Space Agency (ESA) Director-General, Jean-Jacques Dordain, to advise the initiative. "Things are moving in the United States and it was high time there was an initiative in Europe," said Dordain, "I am glad the first initiative is coming from Luxembourg. It will give no excuse for European investors to go to California,"<sup>61</sup> referring to Silicon Valley, the U.S. tech epicenter.

Some felt that a move to Luxembourg by American companies undercut the efforts of the U.S. government to establish a regulatory framework supportive of the space mining industry. "Some voiced their concerns that we were abandoning ship," said Kfir. "But it's like any other multi-national industry; corporations have locations in multiple countries but are headquartered in their home country. We're still an American company. Congress thought that we'd be given more leniency abroad, but that's not what's happening. Title IV of the CSLCA was a huge catalyst in enabling international legislation, which will be based on the U.S. law."<sup>62</sup> Marquez echoed his competitor's sentiments: "We're glad Congress passed the law here in the United States because we can see how it's being replicated in other places. It will be the foundation for future legislation."

### *A race to the regulatory bottom?*

While Luxembourg's promise of a regulatory sanctuary enticed companies discouraged by bureaucratic inefficiencies, it raised some policymakers' concerns. They worried that the recent actions of the United States and then Luxembourg would start a trend in which nations prioritized national and private interests over international cooperation. "[We are] fully aware of the need to reassure industry and investors on the fact that someday there will be the question of what can be done with the resources in outer space," said the Belgian representative at the 2016 COPUOS subcommittee meeting on legal matters. "[But] do we really want to move towards a situation of first come first served, where some would have de facto resources in hand and others would have to pick

up the crumbs?"<sup>63</sup> "I don't believe in first come first served at all," responded the delegate from Mexico.<sup>64</sup>

These critics argued that the slow pace of traditional space policymaking was not accidental. It provided time for the full range of interested parties to debate the possible and uncertain effects of space development. "We need to make practical efforts to turn back the page of history," the Russian delegate argued. "The best mechanism to exchange points of view and present the positions of states, we believe, would be to set up a special working group within the legal subcommittee to deal with evaluation and review of the legal aspects of the use of space resources."<sup>65</sup>

The Russian delegate maintained that the United States and Luxembourg were racing ahead without considering the potential consequences: "We hope the authors of these innovative approaches will understand the negative impact these attempts at implementing this new idea could have...Carrying out activities that have an impact on a celestial body entails significant risks for the whole of humanity and should be duly regulated at international level."<sup>66</sup>

Moreover, critics of lighter regulation argued there could be discernible drawbacks to carving up the cosmos for the current needs of humanity and commercial interests, citing the importance of preserving space environments for purely scientific reasons and for future generations' needs. "One idea is to set aside pristine areas of certain planetary bodies as 'planetary parks,' to be left untouched and appreciated for their own sake,"<sup>67</sup> said Linda Billings, professor at George Washington University and advisor to NASA's Office of Planetary Protection. "It is the right of every person to stand and stare across the beautiful barrenness and desolation,"<sup>68</sup> claimed Charles Cockell, astrobiology professor at the University of Edinburgh, and key proponent of the planetary parks concept. He continued:

I think the reasons are two-fold. It is partly scientific and partly ethical. One scientific argument is that it's useful to keep areas of other planetary bodies free of human activity, to maintain pristine conditions that can be used to answer scientific questions. This may turn out to be essential if researchers discover life elsewhere...One ethical argument is that it says something about our species that we think about our actions elsewhere and attempt to mitigate our impact prior to establishing a permanent presence beyond the Earth. We might want to preserve some places in pristine condition for future generations. We may also want to protect unknown benefits that could potentially be gained from places in space that human activity has not altered.<sup>69</sup>

## **PRI's decision**

PRI was well positioned to become the world's first space mining company. Not only was the firm more confident in its legal rights after the passage of the CSLCA it had helped to effect, but, in May 2016, the company announced it had successfully raised \$21.1 Million in Series A financing.<sup>70</sup> An ostensibly quixotic endeavor in the past, space mining now seemed to be on the horizon.

If it were to succeed, PRI's strategy could prove to be unimaginably lucrative. "The first trillionaire there will ever be is the person who exploits the natural resources on asteroids," predicted Neil deGrasse Tyson, prominent astrophysicist and director of the Hayden Planetarium, in New York, "There's this vast universe of limitless energy and limitless resources."<sup>71</sup> Moreover, if it succeeded, PRI would kickstart the broader development of a space economy, fulfilling its founders' deepest-held hopes.

But challenges remained. Regulatory ambiguity over property rights, despite the 2015 CSLCA, entrenched uncertainty into the company's strategy, and domestic regulatory friction threatened to slow progress. What strategy could PRI adopt that would be robust to these uncertainties and take advantage of the ways in which they were most likely, perhaps in part due to PRI's efforts, to be resolved? Meanwhile, a stark outside option was now available. Luxembourg claimed to offer greater regulatory protection and financial support for space mining companies. Should PRI set aside the political progress it had vigorously lobbied for in the United States and look abroad?

**Exhibit 1** NASA 2014 Emerging Space report sample of private space companies

Sector	Company	Year Established	Founder	Services
Space Access	Astrobotic	2008	Red Whittaker	Transportation to the Moon
	Blue Origin	2000	Jeff Bezos	Launch vehicles and engines, space tourism
	Masten Space Systems	2004	Dave Masten	Suborbital launches of small payloads
	Virgin Galactic	2004	Richard Branson	Space tourism
	XCOR Aerospace	1999	Jeff Greason	Suborbital launches, human spaceflight
	Orbital Sciences Corporation	1982	David Thompson, Bruce Ferguson, Scott Webster	Orbital launches of satellites and ISS cargo
	SpaceX	2002	Elon Musk	Launch vehicles, Mars colonization
	Stratolaunch Systems	2011	Paul Allen	Air-launched orbital launch services
	United Launch Alliance	2006	JV: Lockheed Martin & Boeing	Orbital launch services
Remote Sensing	Planet Labs	2010	Will Marshall, Chris Boshuizen, Robbie Schingler	Frequent imaging of the Earth and open access to acquired data via website
	Skybox Imaging	2009	Dan Berkenstock, John Fenwick, Ching-Yu Hu, Julian Mann	Frequent imaging and HD video of Earth, data analysis, and open access to acquired data via website
LEO Human Spaceflight	Bigelow Aerospace	1999	Robert Bigelow	Space habitats
	Boeing	1916	William Boeing	Crewed LEO transportation
	Sierra Nevada Corporation	1963	John Chisholm	Crewed LEO transportation
	Space Adventures	1998	Eric Anderson	Crewed LEO and lunar transportation, space tourism
Beyond LEO	Deep Space Industries	2012	Bryan Versteeg, Rick Tumlinson	Asteroid mining
	Made in Space	2010	Aaron Kemmer, Jason Dunn, Mike Chen, Michael Snyder	Additive manufacturing in space
	Mars One	2011	Bas Lansdorp	Mars colonization
	Moon Express	2010	Bob Richards, Naveen Jain, Barney Pell	Moon exploration and mining
	Planetary Resources, Inc.	2010	Eric Anderson, Peter Diamandis	Asteroid mining
	Shackleton Energy	2008	Jim Keravala	Lunar water harvesting for fuel, Moon colonization

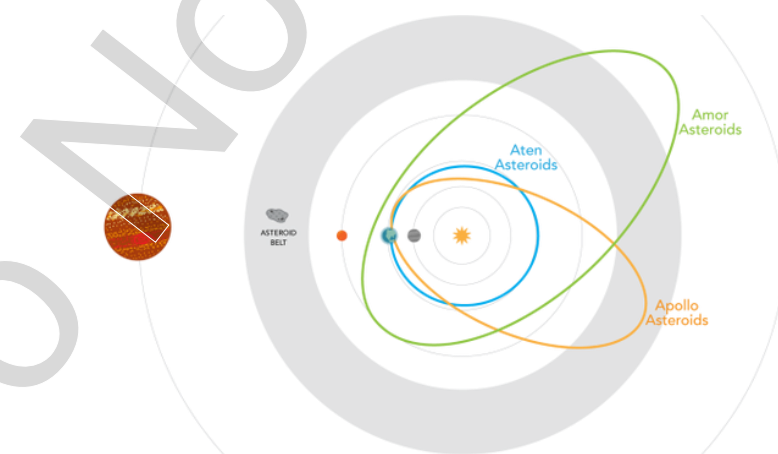
Source: Adapted from NASA "Emerging Space, The Evolving Landscape of the 21<sup>st</sup> Century American Spaceflight, [http://www.space.taurigroup.com/reports/Emerging\\_Space.pdf](http://www.space.taurigroup.com/reports/Emerging_Space.pdf), and compiled from Hoover's Inc., [www.hoovers.com](http://www.hoovers.com), Company Database and Business Alabama <http://www.businessalabama.com/Business-Alabama/October-2013/Stratolaunch-Wants-to-Leapfrog-the-Launch-Pad/>, accessed April 11, 2016.

**Exhibit 2** Asterank asteroid data

Name	Value (\$, billion)	Est. Profit (\$, billion)	Delta-v (km/s)
<b>PRI target NEAs</b>			
2008 HU4			3.911
2011 CG2			4.124
2013 PA7			4.436
Ryugu	95	35.4	4.663
2014 EK24			4.854
2002 TC70			4.893
2001 QC34			4.988
2014 SC324			6.005
<b>Highest valued, most accessible NEAs</b>			
Anteros	5,570	1,250	5.44
2001 CC21	147	29.8	5.636
Ryugu	95	34.5	4.663
1992 TC	84	16.8	5.647
Didymos	62.3	16.4	5.163
1989 ML	13.9	4.38	4.889
2011 UW158	6.7	1.74	5.188
Nereus	4.7	1.39	4.985
2001 SG10	3.5	0.545	5.88
2002 DO3	0.334	0.059	5.896

Source: Compiled by casewriters from Asterank, available at <http://www.asterank.com/>.

Note: Value estimates based on the mass of a given asteroid and its spectral type. Asteroid spectra used to infer composition, which, in conjunction with current market prices, determine potential value. Delta-v calculations estimate the energy expenditure required to reach the asteroids; used as a proxy for accessibility. Profit calculations combined accessibility (biased toward low delta-v) and value; balanced between high value and high distance and energy expenditure.

**Exhibit 3** PRI target asteroids

Source: Company website, <http://www.planetaryresources.com/2015/08/how-we-choose-our-asteroid-targets/>, accessed August 2016.

## Appendix A U.S. Airline Deregulation Act of 1978

### *Motivation for deregulation*

Since 1938, the U.S. airline industry had been regulated as a public utility by the Civil Aeronautical Board (CAB), which set routes and schedules and guaranteed a reasonable rate of return for airlines. In principle, by holding down fares for short-haul routes subsidized by long-haul flights, typically paid for by business travelers who were less sensitive to price increases, CAB could ensure demand from low traffic locations and encourage airlines to expand their networks to smaller cities. But bureaucratic complacency caused delays and often denied airlines' applications for new routes or fare changes.

Moreover, the protection offered by the federal government supported the oligopolistic nature of the industry, allowing airlines to raise costs to consumers. When the oil crisis of the 1970s drove fuel prices up 222% between 1969 and 1978 and general inflation took hold, airfares soared.<sup>8</sup>

As a result, Congress felt pressure for reform. "We want to take the heavy hand of the federal government out of economic regulation of the airline industry, to permit the travelers of this country to pay lower fares, and so eventually to benefit the American consumer," explained U.S. Senator Ted Kennedy, a chief driver of the proposed legislation, "We want to permit greater flexibility for innovative firms to compete in the airline industry."<sup>72</sup>

### *Opposition*

While most experts at the time agreed that deregulation would improve efficiencies, lower federally-controlled barriers to entry for new airlines, and bring down passenger airfares, support for the regulated regime remained. In particular, incumbent airline companies argued that without regulation they would be forced to focus on high volume and high profit routes and pass over lower traffic destinations. At a roundtable discussion of the deregulation proposal in 1977, Albert Casey, president of American Airlines argued,

I simply do not accept the argument that we have to encourage competition to a greater degree than at present. There has not been a society in the history of the world that has not had to regulate its transportation. Transportation is a *quasi*-public utility that does not enjoy the ability to build an inventory. Thus, it must have responsible price regulation in order to protect its huge capital investments.<sup>73</sup>

Casey was not alone in his dissent. Edwin Colodny, president of then Allegheny Airlines (which would change its name to US Airways in 1997 and merge with American Airlines in 2015) contended, "We should not throw out regulation and substitute chaos...the cure proposed may, unfortunately, be worse than the disease, because the opportunity to earn adequate levels of profits under the proposed system may be available only to a very few larger airlines."<sup>74</sup> Colodny's prediction of further market concentration as a result of deregulation would ultimately play out.

A second group that contested deregulation was the airline labor union. They feared that airlines would be less likely to comply with union demands if they could not pass increased wage costs on to the customer. "[W]e are flatly opposed to the current proposal," said Frank Waldner, Director of the

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<sup>8</sup> See Anita M. McGahan and Julia Kou, "The U.S. Airline Industry in 1995" HBS 795-113 for an in-depth discussion of the deregulation of the U.S. airline industry and its aftermath.

International Association of Machinists and Aerospace Workers OSHA Department, continuing, "It is an unnecessary step and will create havoc in the industry."<sup>75</sup>

A third critique was that deregulation threatened to undermine safety standards. "Air carriers could afford [high] levels [of safety] in the regulated environment," explained Peter Loeb, professor of economics at Rutgers University. In the deregulated environment, Loeb argued, airlines would be "engaged in cost cutting in maintenance, training, operations, and wages to some extent to stay viable."<sup>76</sup>

### *Outcome and lessons learned*

Almost immediately after the 1978 U.S. Airline Deregulation Act, which disbanded CAB, a national economic downturn hindered new airline entrants' ability to compete. Major airlines continued to dominate the market, in part by implementing predatory pricing schemes. By incurring massive losses to cut out competition, major airlines forced themselves into bankruptcy. Between 1978 and mid-2001, nine of the major airlines and over one hundred smaller carriers went bankrupt or were liquidated. By filing for Chapter 11 bankruptcy protection, airlines could restructure and reemerge, often effectively dismantling labor unions by firing and subsequently rehiring their entire workforce at substantially lower pay. The Act's intended objective to reduce unnecessary industry consolidation had backfired; prior to deregulation 90% of the market was controlled by ten major airlines, however, by 2013, just four companies held 85% market share.

Expert opinion of the effect of deregulation on passengers was mixed. The Air Transport Association found that in the 40 years following 1978, airfares dropped 44.9% in real terms. However, a study by David B. Richards, a former analyst with CAB and the FAA, concluded that "the grant of pricing freedom to the airline industry has generally resulted in average prices being higher than they would have been had regulation continued."<sup>77</sup>

By the mid-1990s and into the 2000s, as bankruptcy, mergers, and acquisitions inundated the industry, debate over the merits of reregulation reemerged. Robert Crandall, the former CEO of American Airlines, commented, "I suspect some middle ground between the regulation we had prior to 1978 and what we have today is probably a better public policy." Even those who had supported deregulation in the 1970s were critical upon reflection. "What does the industry's history tell us? Was the effort worthwhile?" Supreme Court Justice Stephen Breyer, who had worked on the 1978 legislation, asked in 2011, "Certainly it shows that every major reform brings about new, sometimes unforeseen, problems."<sup>78</sup>

Source: Compiled by casewriters from Stover, John F. (1997). *American Railroads*. University of Chicago Press. p. 234; <https://www.aei.org/publication/what-is-it-should-we-have-it-how-much-competition-in-the-airlines/>; [http://www.centennialofflight.net/essay/Commercial\\_Aviation/Dereg/Tran8.htm](http://www.centennialofflight.net/essay/Commercial_Aviation/Dereg/Tran8.htm); <http://www.cnn.com/id/45477274>; [http://www.huffingtonpost.com/david-morris/airline-deregulation-ideology-over-evidence\\_b\\_4399150.html](http://www.huffingtonpost.com/david-morris/airline-deregulation-ideology-over-evidence_b_4399150.html); Fred L. Smith Jr. and Braden Cox, "Airline Deregulation." *The Concise Encyclopedia of Economics*. 2008. Library of Economics and Liberty. 8 August 2016. <<http://www.econlib.org/library/Enc/AirlineDeregulation.html>>; and <http://www.bloomberg.com/news/articles/2011-01-20/airline-deregulation-revisitedbusinessweek-business-news-stock-market-and-financial-advice>.

## Appendix B Parallels on Earth

### *The Antarctic Treaty*

International agreements concerning the peaceful and cooperative use of outer space were inspired by compromises governing national and private interests on Antarctica. In the 1960s, as U.S. rocketry capabilities advanced and the Soviet Union tested its intercontinental ballistic missiles, President Eisenhower urged the UN General Assembly to consider principles of the recent Antarctic Treaty, enacted in 1959 as the first "nonarmament" agreement amidst the extraordinary Cold War-era tensions, as a model for outer space.<sup>79</sup>

While the Antarctic Treaty established the continent as a scientific preserve, explicitly banning military activity and intentionally neglecting to establish a regulatory framework for territorial sovereignty, property rights, or economic activity, several nations had already laid territorial claims on regions of the continent prior to the Treaty's enactment. By authorizing the Antarctic Treaty, the international community banned the staking of further claims by any nation. Signatories recognized the need to ensure peace in the region and to settle sovereignty concerns but did not establish an administrative body to oversee implementation and adjudication of disputes, instead deferring to the UN International Court of Justice to settle disagreements should they arise.

The United States and the Soviet Union were among the twelve original signatories of the Antarctic Treaty. Although both nations were engaged in exploration on the continent, neither had exerted sovereignty over territory on Antarctica. Neither recognized the claims of any other governments, though they reserved the right to assert claims in the future.

The Antarctic Treaty also limited economic opportunities on the Polar Shelf. After a failed attempt to establish mineral rights in Antarctica in the early 1980s, the Protocol on Environmental Protection to the Antarctic Treaty was passed in 1998. The Protocol established the Committee for Environmental Protection (CEP) and banned all mining activities in Antarctica, deeming the continent a "natural reserve devoted to peace and science."<sup>80</sup> Consequently, economic development opportunities for Antarctica remained frozen, limited to scientific and tourist expeditions.

### *The Law of the Seas*

The debate over space mining resembled in many ways a contemporaneous debate over the use of resources in the vast open waters on Earth. Policymakers and business leaders trying to shape and anticipate the future of the space resources sector could look to its story for insights.

The UN Convention on the Law of the Seas (UNCLOS), which ran from 1973 to 1982, confronted a tension that global regulators faced between economic development and conservation in the Earth's oceans and seas. In response to nations' demands for access to the sea's resources, the Convention extended the zone of national sovereignty over coastal waters from the traditional three nautical miles to 200 nautical miles out to sea. Beyond 200 miles, however, in "international waters," the signatories agreed to limits on deep-sea fishing, pollution, and mining to be monitored and enforced by a new International Seabed Authority (ISA). The ISA could grant parties licenses to prospect or explore regions outside their sovereign territory, but no regulations for exploiting those resources were put into place.<sup>81</sup>

The United States refused to ratify UNCLOS, claiming that its omission of a licensing regime that protected both the environment and the property rights of investors in deep-sea resource extraction blocked maritime economic development.<sup>82</sup> Instead, the United States passed the Deep Seabed Hard

Mineral Resources Act in 1980 to govern the deep seabed mining activities of domestic entities. The Act “sets forth necessary criteria for an international regime to be acceptable to the United States. These include access for U.S. citizens to deep seabed resources and assured continuity in mining activities undertaken by U.S. prior to an international regime under terms, conditions, and restrictions which do not impose significant new economic burdens.”<sup>83</sup>

The U.S.’s actions were sharply criticized by supporters of UNCLOS’s incremental approach to deep seabed mining. They argued that policymakers should learn from the environmental damage caused by modern terrestrial mining operations. A group of maritime science and law researchers wrote, in the *World Ocean Review*, that UNCLOS “contrasts starkly with the situation onshore, where regardless of the type of resources – coal, oil or gas – exploitation has invariably taken precedence, resulting in environmental degradation, until it was recognized that mistakes had been made and remedial action should be taken...The absence of a regulatory regime for exploitation [in UNCLOS] is due in part to a number of unresolved environmental issues.”<sup>84</sup>

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