Developing a Law of Asteroids: Constants, Variables, and Alternatives

The proposition of mining an asteroid for natural resources is quickly moving from the realm of science fiction into viable reality. As a review of the relevant literature and domestic and international laws makes clear, the legal status of an asteroid-mining venture, or any property rights developing from such a venture, remains doubtful. Several potential legal principles or regimes have been discussed in the literature, such that there would be limited value in offering another. Instead, this Note gives the legal problems a firmer foundation in scientific experience, weighs the merits and shortcomings of the extant proposals, considers which empirical variables should shape any future legal approach to asteroid law, and addresses some of the more general challenges of making law prospectively, especially in the transnational context.

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INTRODUCTION: RAINING DIAMONDS

It was Tuesday, April 24, 2012, and astronomer Peter Jenniskens was driving toward the town of Lotus, California, hoping to beat the rain.[1] Two days earlier, a meteor[2] the size of a large car had burned through the atmosphere above Nevada and California, heading west, until it ultimately broke up high above the towns of Lotus and Coloma, California, raining down small pieces of black rock.[3] By Wednesday, the rain would contaminate the meteorite pieces, so Jenniskens, together with professional meteorite-hunter Robert Ward, had little time to waste.[4]

Ultimately, they found two pieces of meteorite, neither more than a few grams in weight, before the rain came.[5] Over the following months, volunteers and locals would turn in dozens more fragments.[6] Scientists found that the pieces contained an astonishing array of substances: manganese and chromium, both metals with important industrial applications; pieces of oldhamite, a rare mineral thought to date back to the formation of the solar system; amino acids, the chemical building blocks of life; and, most notably of all, two tiny diamonds, microns across, embedded in the rock.[7]

That diamonds would rain from the heavens on the town of Coloma was a striking coincidence. It was there, in 1848, that John Marshall found a nugget of gold at Sutter's Mill, sparking the California Gold Rush.[8] As evidence accumulates that asteroids contain valuable natural resources in extraordinary quantities, a new race is

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1. Emily Underwood, *Sutter's Mill Meteorite Produces Mother Lode of Research*, 338 SCIENCE 1521, 1521 (2012), http://www.sciencemag.org/content/338/6114/1521.full.

2. The small bodies of the solar system are asteroids, mostly made of rock, or comets, which contain a substantial quantity of ice. A meteoroid is a small asteroid or comet; when one enters Earth's atmosphere, it is called a meteor; if one touches down on Earth's surface, it is called a meteorite. *Asteroid Fast Facts*, NASA (Mar. 31, 2014), http://www.nasa.gov/mission_pages/asteroids/overview/fastfacts.html#.VK5hjCvF9yw.

3. Underwood, *supra* note 1.

4. *Id.*

5. *Id.*

6. *Id.*

7. *NASA Scientists Find Diamonds and Other Treasures in Gold Rush Meteorite*, NASA (Nov. 7, 2014), http://www.nasa.gov/ames/nasa-scientists-find-diamonds-and-other-treasures-in-gold-rush-meteorite.

8. *Gold Nugget*, AM. MUSEUM NAT. HIST., http://americanhistory.si.edu/collections/search/object/nmah_741894 (last visited Feb. 29, 2016).

beginning.[9]

Already, corporate interests are making credible long-term plans to send a space probe to an asteroid, mine it for resources, and bring those resources back to Earth.[10] One expert equated the asteroid-mining industry to "the Internet in 1986."[11] But under what law? A single asteroid may contain trillions of dollars' worth of materials,[12] yet no asteroid is under the jurisdiction of any state.[13] What property rights, if any, should an asteroid-mining venture have in its target asteroid prior to reaching it? While on-site? Once the extracted resources are brought back to Earth, or once they have been put to some other useful purpose?

This Note begins by discussing the present state of the nascent asteroid-mining industry: why asteroids are a valuable target, what kinds of entities are currently developing plans to mine them, and what an asteroid-mining mission might look like. It proceeds to the present state of asteroid-mining law and catalogues recent proposals for a law of asteroids. Finally, it proposes a framework of desired outcomes and relevant empirical variables with which to evaluate asteroid-mining proposals and considers the present proposals in the context of that framework.

I. THE STATE OF THE ART

The theorized richness of resources in asteroids, together with humankind's rapidly developing technical capabilities, has produced a burgeoning interest in the commercial extraction of resources from asteroids. To understand the legal questions in their full complexity, it is useful to briefly outline why asteroids are a particularly attractive

9. *See infra* Part I.B.

10. *Id.*

11. Jonathan Blitzer, *The Age of Asteroids*, NEW YORKER (Dec. 10, 2014), http://www.newyorker.com/tech/elements/age-asteroids (quoting Rosanna Sattler).

12. *See infra* Part II.

13. See the discussion of the Outer Space Treaty *infra* Part II. Initial efforts to conceptualize outer space as part of the "common heritage of mankind," the legal category into which lawmakers have placed the deep seabed and its resources, essentially petered out with the failure of the Moon Agreement, also discussed *infra* Part II. Austin C. Murnane, *The Prospector's Guide to the Galaxy*, 37 FORDHAM INT'L L.J. 235, 267 (2013) ("The United Nations, or one of its subsidiaries, cannot establish that an asteroid and its resources are the common heritage of mankind because the 'common heritage' principle is not a true international norm."); Scott J. Shackelford, *The Tragedy of the Common Heritage of Mankind*, 28 STAN. ENVTL. L.J. 109, 149 (2009).

target, what sorts of enterprises are interested in mining the sky, and what the earliest asteroid-mining missions might look like.

A. Why Mine an Asteroid?

Implicit in the premise of this Note, and of every scholarly treatment of the possibilities in asteroid mining, is that asteroids present a uniquely attractive object for human endeavor. Why should mining an asteroid be of greater interest to a celestial prospector than the Moon or Mars? The value of asteroids has not been directly proven, inasmuch as humankind has never mined an asteroid or substantially sampled an asteroid's contents, except in the form of meteorites that fall to Earth.[14] Nevertheless, astronomers believe that because of the process by which asteroids were formed, a small portion of the millions and millions of asteroids orbiting the sun are rich in valuable natural resources: platinum, rhodium, osmium, iridium, palladium, rhenium, and other rare metals, embedded in nickel and iron.[15]

At the time of writing, platinum was available on the open market for $827.70 an ounce.[16] Platinum has a wide range of industrial applications on Earth—in catalytic converters and other technologies that reduce carbon emissions from motor vehicles; in nearly all

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14. While scientists have drawn some conclusions about asteroid composition from meteorites that have fallen to Earth, "in general it is not straightforward to link meteorite types based on mineralogy with asteroid classes based on spectrometric observations." Mikael Granvik et al., *Earth's Temporarily-Captured Natural Satellites—The First Step Towards Utilization of Asteroid Resources*, *in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 151, 151 (Viorel Badescu ed., 2013).

15. Martin Elvis, *Prospecting Asteroid Resources*, *in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 81, 85–88 (Viorel Badescu ed., 2013). In brief, scientists believe that asteroids originated in "planetisemals": rocky bodies that formed around the sun during the earliest stages in the development of the solar system. Diego Turrini et al., *Probing the History of Solar System Through the Cratering Records on Vesta and Ceres*, 413 MONTHLY NOTICES ROYAL ASTRONOMICAL SOC'Y 2439, at *1 (2011), http://arxiv.org/pdf/0902.3579.pdf (page references are to the arXiv.org version of text). The planetesimals had molten cores, which caused the heavier elements inside, including the platinum-group metals, to sink toward the center. *Id.*; *Asteroids: Read More*, NASA, http://solarsystem.nasa.gov/planets/profile.cfm?Object=Asteroids&Display=OverviewLong (last visited Feb. 17, 2016). Although most asteroids were originally part of the planetesimals' crusts, and therefore are comprised mostly of carbon, a few are fragments of the planetesimal cores and are made in large or whole part of valuable metals suspended in nickel and iron. *See generally* Elvis, *supra*.

16. *Platinum*, NASDAQ, http://www.nasdaq.com/markets/platinum.aspx (last visited Feb. 17, 2016).

modern electronic devices; and in a wide array of other products, including fertilizers and high-octane gasoline.[17] Other platinum-group metals are similarly valuable, and the nickel and iron in which they are situated have some economic value as well.[18] Thus, one distinguished astronomer, writing in 1996, estimated the total value of the *smallest* known metallic asteroid at $20 trillion.[19]

Even non-metallic asteroids may prove valuable to future human endeavors, however, because they have the advantage of not being on Earth.[20] Launching an object from the surface of the Earth to orbit is a fantastically expensive proposition: the traditional figure is $10,000 per pound, although developments in recent years have reduced the price to $2,000 or $3,000 per pound, and SpaceX, a major private spaceflight company, claims its spacecraft will further reduce the price to $1,000 per pound.[21] Even the lowest of these prices leaves a wide margin for any enterprise that can find an extraterrestrial source for materials that would otherwise have to be sent up from Earth.[22] Asteroids have the potential to be such a source. The

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17. *Platinum-Group Elements—So Many Excellent Properties*, U.S. GEOLOGICAL SURV. (July 2014), http://pubs.usgs.gov/fs/2014/3064/pdf/fs2014-3064.pdf.

18. Rhodium, for instance, was most recently trading at about $725 per ounce. *Rhodium*, KITCO, http://www.kitco.com/charts/rhodium.html (last visited Apr. 12, 2016). Nickel was most recently trading at $8,500 per ton. *LME Nickel*, LONDON METAL EXCHANGE, http://www.lme.com/metals/non-ferrous/nickel (last visited Apr. 12, 2016). Planetary Resources estimates that "1 of 4 industrial goods on Earth require [platinum-group metals] in production." *Market for Metals in Space*, PLANETARY RESOURCES, http://www.planetaryresources.com/asteroids/market-for-metals (last visited Feb. 17, 2016).

19. JOHN S. LEWIS, MINING THE SKY: UNTOLD RICHES FROM THE ASTEROIDS, COMETS, AND PLANETS 112 (1996).

20. Charles R. Nichols, *Volatile Products from Carbonaceous Asteroids*, *in* RESOURCES OF NEAR-EARTH SPACE 543, 544–46 (John S. Lewis, Mildred Shapley Matthews & Mary L. Guerrieri eds., 2013), http://www.uapress.arizona.edu/onlinebks/ResourcesNearEarthSpace/resources21.pdf.

21. David Kestenbaum, *Planet Money: Spaceflight Is Getting Cheaper. But It's Still Not Cheap Enough.*, NPR (July 21, 2011, 12:01 AM), http://www.npr.org/blogs/money/2011/07/21/138166072/spaceflight-is-getting-cheaper-but-its-still-not-cheap-enough.

22. Significantly, it is much cheaper to move an object from orbit back to Earth. Achieving orbit is essentially a matter of speed; getting to orbit is expensive in part because one must accelerate up to a suitable speed very quickly, which requires a great deal of fuel. Deorbiting, then, is a matter of shedding that speed, which can be done by skimming through the Earth's atmosphere or using a parachute. *Basics of Space Flight: Gravitation and Mechanics*, NASA, http://www2.jpl.nasa.gov/basics/bsf3-4.php (last visited Feb. 29, 2016); *Mars Climate Orbiter—Aerobraking*, NASA, http://mars.jpl.nasa.gov/msp98/orbiter/aerobrake.html (last visited Feb. 29, 2016); *Hayabusa—A Technology Demonstrator for Sample and Return*, JAXA 4, http://global.jaxa.jp/projects/sat/muses_c/files/hayabusa_return.pdf (last visited Feb. 29, 2016).

C-class asteroids are thought to be rich in water, carbon dioxide, carbon monoxide, ammonia, methane, and other "volatile" substances that could be used for fuel or life-support purposes, among others.[23] By mining a near-Earth asteroid and devoting its volatile resources to supporting space exploration or inhabitance, a venture could offer a cheaper alternative to launching resources from Earth's surface.

As various analyses suggest, asteroid mining, under proper conditions and with the right technology, could prove economically viable, either to supply Earth or to serve as the natural resource base for other in-space operations.[24]

B. Who Are the Asteroid Miners?

Asteroid mining has increasingly attracted high-profile backing from the business world. Planetary Resources, a company committed to extracting water and platinum-group metals from asteroids, lists Larry Page, the Chief Executive Officer of Google parent company Alphabet, Eric Schmidt, Alphabet's executive chairman, and Richard Branson, founder of the Virgin family of companies, among its founding investors, and Dante Lauretta, principal investigator in charge of the upcoming OSIRIS-REx mission,[25] as one of its scientific advisors.[26] The company recently released a list of eight potential target asteroids for commercial mining operations,[27] and on Oc-

23. Nichols, *supra* note 20, at 544–46.

24. For detailed economic analyses, see, for example, Mark J. Sonter, *The Technical and Economic Feasibility of Mining the Near-Earth Asteroids*, 41 ACTA ASTRONAUTICA 637, 638. *See generally* Shane D. Ross, *Near-Earth Asteroid Mining*, VA. TECH (Dec. 14, 2001), http://www2.esm.vt.edu/~sdross/papers/ross-asteroid-mining-2001.pdf; Adam Mann, *Tech Billionaires Plan Audacious Mission to Mine Asteroids*, WIRED (April 23, 2012), http://www.wired.com/2012/04/planetary-resources-asteroid-mining ("Platinum alone is worth around $23,000 a pound—nearly the same as gold. Mining the top few feet of a single modestly sized, half-mile-diameter asteroid could yield around 130 tons of platinum, worth roughly $6 billion."). Planetary Resources also makes the case for asteroid mining's economic viability. *Market for H2O*, PLANETARY RESOURCES, http://www.planetaryresources.com/asteroids/market-for-h2o (last visited Feb. 29, 2016) ("The present day space economy spends Billions [sic] on rocket fuel each year to propel spacecraft into their final orbits and to keep those spacecraft safely in their positions. Water from asteroids can be broken down into Hydrogen Oxygen-based rocket fuels in order to meet this growing demand.").

25. *See infra* Part I.C.4.

26. *Team*, PLANETARY RESOURCES, http://www.planetaryresources.com/company/#team (last visited Apr. 12, 2016).

27. *Targets of Interest*, PLANETARY RESOURCES, http://www.planetaryresources.com/asteroids/#asteroid-targets (last visited Feb. 23, 2016).

tober 28, 2014, attempted to launch a satellite to test some of the technologies integral to its resource-extraction plan.[28] Space-law expert Rosanna Sattler recently described Planetary Resources as "the new Dutch East India Company."[29]

Deep Space Industries (DSI), another asteroid-mining endeavor, has announced a plan to launch a network of small, low-cost prospecting spacecrafts to scout out potential targets for asteroid mining.[30] DSI's chief scientist, John Lewis, is a distinguished scholar.[31] The company was recently selected by the National Aeronautics and Space Administration (NASA) to conduct economic and technical studies pertaining to asteroid mining.[32] Several other companies are developing technologies to facilitate the extraction of resources from asteroids.[33]

C. What Will It Look Like?

The unique challenge of contemplating the law of a future industry is that the author can essentially choose his or her own facts by making more or less realistic predictions about what the future will look like; there is no empirical baseline. To reach useful legal conclusions, however, it is more helpful to assume that the first asteroid-mining missions will involve only incremental improvements on current scientific missions.[34] To understand the challenges of asteroid mining, then, it is useful to review humankind's recent and

28. *How We Are Moving Forward!*, PLANETARY RESOURCES (Oct. 31, 2014), http://www.planetaryresources.com/2014/10/moving-forward. The unmanned NASA rocket carrying the satellite in its cargo self-destructed on launch, dealing Planetary Resources a setback. *See generally* Brad Scriber, *Why NASA Blew up a Rocket Just After Launch*, NAT'L GEOGRAPHIC (Oct. 31, 2014), http://news.nationalgeographic.com/news/2014/10/141030-first-person-rocket-explosion-antares.

29. Blitzer, *supra* note 11 (quoting Rosanna Sattler).

30. *Prospecting for Space Resources*, DEEP SPACE INDUSTRIES, http://deepspaceindustries.com/prospecting (last visited Feb. 23, 2016).

31. Lewis is the author of MINING THE SKY: UNTOLD RICHES FROM THE ASTEROIDS, COMETS, AND PLANETS (1996), one of the foundational texts on resource extraction from outer space. *Team Bios*, DEEP SPACE INDUSTRIES, https://deepspaceindustries.com/team/team-bios/#john (last visited Feb. 23, 2016).

32. *NASA Selects Studies for the Asteroid Redirect Mission*, NASA (June 19, 2014), http://www.nasa.gov/content/nasa-selects-studies-for-the-asteroid-redirect-mission.

33. *See id.*

34. *See* Shackelford, *supra* note 13, at 166 (concluding that the Moon Treaty failed because "drafters attempted to develop binding rules decades ahead of the necessary technology").

current efforts, and plans for the near future, to reach asteroids and comets. We can presume that the first asteroid-mining mission will face many of the same challenges: difficulties in reaching asteroids, landing on them, and returning safely to Earth.

1. NEAR Shoemaker

The story of human exploration of the asteroids began in earnest fourteen years ago, when NASA administrators decided to terminate the mission of a space probe called NEAR Shoemaker.[35] Shoemaker launched on February 17, 1996, and had spent three years on a circuitous and hazardous journey to an asteroid called Eros, an oblong asteroid measuring twenty-one miles from fore to aft.[36] For nearly a year, Shoemaker had orbited around Eros and sent back pictures and data of the tiny alien world.[37] By February 2001, however, the costs of the Shoemaker program were mounting and the probe's fuel supply was dwindling; NASA administrators ordered that the probe be shut down.[38]

The scientists attached to the NEAR mission decided to end Shoemaker's journey by having it do something it had never been designed or intended to do: land on the asteroid.[39] Even though Shoemaker had no landing legs, no specialized landing engines, and no airbags, NASA operators nevertheless managed to execute a perfect three-point landing: Shoemaker, having been more or less crashed into the surface of an asteroid as slowly as possible, survived with most of its functions intact.[40] For seventeen days in February 2001, scientists gathered data directly from the surface of an asteroid for the first time.[41] By the end of the month, however, Shoemaker's landing site was rotating out of direct sunlight and temperatures were dropping precipitously.[42] After two and a half weeks, NASA scientists finally closed out contact with Shoemaker, the first man-made object to have made physical contact with an asteroid.[43]

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35. HOWARD E. MCCURDY, NASA, LOW-COST INNOVATION IN SPACEFLIGHT: THE NEAR EARTH ASTEROID RENDEZVOUS (NEAR) SHOEMAKER MISSION 47 (2005).

36. *Id.* at 35, 46.

37. *Id.* at 46.

38. *Id.* at 47.

39. *Id.* at 47–48.

40. *Id.* at 49.

41. *Id.*

42. *Id.*

43. *Id.* at 2.

The experience of Shoemaker indicates some of the challenges facing any effort to explore asteroids. The lack of fidelity of communications between Earth and a distant space probe, for example, means that the space vehicle must be designed and programmed prior to launch to function with a relatively high degree of autonomy.[44] Even minor flaws in the initial design can thus prove difficult to correct once the mission is underway: Shoemaker, for instance, nearly missed the asteroid altogether due to a minor technical flaw, the correction of which cost the probe a great deal of fuel and over a year's delay.[45] And even once Shoemaker had successfully touched down, it had to contend with the remarkably unforgiving conditions peculiar to asteroids[46]: temperatures, for instance, ranged over five hundred degrees Fahrenheit, depending on whether or not Shoemaker was directly exposed to the sun.[47] Any asteroid mining mission would have to contend with similar challenges.

2. Hayabusa

In 2005, a Japanese spacecraft called Hayabusa touched down on Itokawa, a distant asteroid, after a journey of two years and a billion kilometers.[48] Although its original plan—to capture fragments of Itokawa's surface by firing projectiles into the asteroid—was scuttled by technical difficulties, Hayabusa still managed to capture particles of dust kicked up by its landing on the asteroid's surface.[49] After a five-year return trip, Hayabusa touched down in 2010 in the Australian outback, carrying with it thousands of microscopic particles from another world.[50]

Hayabusa's experience, like that of Shoemaker, suggests the high degree of risk associated with any asteroid-mining venture. For

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44. *See id.* at 43.

45. *Id.* at 43–44.

46. *See id.* at 46 (describing the technical difficulties posed by Eros' low gravity and irregular shape).

47. *Id.* at 49; *see also* Simon D. Fraser, *Electric Power System Options for Robotic Miners*, *in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 247, 250 tbl.10.2 (Viorel Badescu ed., 2013) (observing that the temperature range on asteroids can exceed the range on the Moon).

48. *Asteroid Itokawa Sample Return*, NASA (Dec. 29, 2010), http://science.nasa.gov/science-news/science-at-nasa/2010/30dec_samplereturn.

49. *Id.*

50. *Id.* Japan's right to ownership of the returned dust samples has apparently never been seriously doubted, and today they are preserved in a Japanese museum. 126 CONG. REC. H3,518 (daily ed. May 21, 2015) (statement of Rep. Posey).

example, a solar flare hit the vehicle early in its voyage, damaging the solar panels and forcing the craft to travel more slowly than had been planned.[51] Two reaction wheels on the vehicle failed en route, substantially limiting the probe's maneuverability.[52] Perhaps as a result, the first attempt to land the probe on Itokawa failed spectacularly, with Hayabusa bouncing off the surface twice before engineers aborted the effort.[53] More to the point, the core technology for extracting samples from the asteroid—the projectiles—failed altogether.[54]

Clearly, Hayabusa would have never returned samples at all—not even microscopic ones—but for the commendable efforts of the Japanese space agency.[55] The challenges it faced show that an effortless, risk-free venture to an asteroid remains a thing of science fiction.

3. Rosetta and Philae

Most recently, on November 12, 2014, the world watched as a small craft operated by the European Space Agency (ESA) touched down on a comet designated 67P/Churyumov–Gerasimenko.[56] The lander, called Philae, had been carried to the comet aboard a larger probe called Rosetta over a ten-year journey that took it past Mars and several asteroids en route to the remote comet.[57] Rosetta is currently orbiting around 67P.[58] On November 12, Philae detached from

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51. *Hayabusa*, NASA, http://science.nasa.gov/missions/hyabusa (last visited Feb. 23, 2016).

52. *Id.*

53. *Id.*

54. *Asteroid Itokawa Sample Return*, *supra* note 48.

55. *See Hayabusa*, *supra* note 51.

56. *Pioneering Philae Completes Main Mission Before Hibernation*, EUR. SPACE AGENCY (Nov 15. 2014), http://www.esa.int/Our_Activities/Space_Science/Rosetta/Pioneering_Philae_completes_main_mission_before_hibernation. Comets, unlike asteroids, are largely or mostly composed of water ice and other "volatile" materials that turn into gas when heated by the sun, mixed with rocks and dust; they are sometimes described as "dirty ice-balls." Recent research, however, suggests that comets and asteroids are more alike than they are different. *Rosetta's Frequently Asked Questions*, EUR. SPACE AGENCY, http://www.esa.int/Our_Activities/Space_Science/Rosetta/Frequently_asked_questions (last visited Apr. 17, 2016). As discussed *supra* note 23–24 and accompanying text, "volatiles" may prove as viable as the platinum-group metals for extraction.

57. *The Long Trek*, EUR. SPACE AGENCY, http://www.esa.int/Our_Activities/Space_Science/Rosetta/The_long_trek (last visited Feb. 16, 2016).

58. *Rosetta and Philae: One Year Since Landing on a Comet*, EUR. SPACE AGENCY,

Rosetta and made a slow descent to the surface.[59] Philae featured multiple systems for securing its landing on Comet 67P—two harpoons, which would tether it to the surface, plus three drills that would screw its feet into the ice.[60] None of these systems activated successfully, causing the probe to bounce twice off of 67P before settling in a poor landing spot.[61] Philae now clings to the comet's icy surface, having transmitted an initial batch of data and currently hibernating until its solar panels can collect enough energy to permit further scientific investigation.[62] As with Shoemaker and Hayabusa before it, Rosetta demonstrates the extent of human spaceflight capabilities and the ways in which our abilities in design, engineering, and execution continue to fall short.

4. Upcoming Missions

A brief survey of planned and ongoing missions suggests the gradual advancements in technological capabilities we can expect in the coming decade.

On December 3, 2014, for instance, the Japanese space agency successfully launched a successor probe to Hayabusa, called Hayabusa 2, which will use explosives to create an artificial crater in asteroid 1999 JU3, land three different probes in the crater, and return samples from deep within the asteroid to Earth.[63]

Meanwhile, NASA's planned OSIRIS-REx spacecraft, which is scheduled to lift off in 2016, will make a three-year journey to a nearby asteroid catalogued as 1999 RQ36.[64] Once there, it will skim the surface of the asteroid, kick up dust with a pneumatic gas gun,

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http://www.esa.int/Our_Activities/Space_Science/Rosetta/Rosetta_and_Philae_one_year_since_landing_on_a_comet (last visited Feb. 16, 2016) [hereinafter *Rosetta and Philae*].

59. *Id.*

60. *Landing on a Comet*, EUR. SPACE AGENCY (Nov. 8, 2014), http://sci.esa.int/rosetta/54470-landing-on-a-comet.

61. *Rosetta and Philae*, *supra* note 58.

62. *Three Touchdowns for Rosetta's Lander*, EUR. SPACE AGENCY, http://www.esa.int/Our_Activities/Space_Science/Rosetta/Three_touchdowns_for_Rosetta_s_lander (last visited Feb. 16, 2016).

63. *Asteroid Explorer "Hayabusa2,"* JAPAN AEROSPACE EXPLORATION AGENCY, http://global.jaxa.jp/projects/sat/hayabusa2 (last visited Feb. 16, 2016).

64. Kris Zacny et al., *Asteroids: Anchoring and Sample Acquisition Approaches in Support of Science, Exploration, and* In situ *Resource Utilization*, *in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 287, 296 (Viorel Badescu ed., 2013).

and collect the samples with a specialized filter.[65]

Even more ambitious missions are in the works. In 2013, NASA announced preliminary work on a space probe that would rendezvous with an asteroid and haul it close enough to Earth for astronauts to visit the captured space object and take samples.[66] The mission's current timeline would have the rendezvous take place by 2022, a date that some planetary scientists have criticized as impossibly optimistic.[67]

In light of the current state of the art in accessing asteroids, it is easy to imagine the kinds of challenges the initial asteroid-mining missions will face. As Shoemaker, Hayabusa, and Philae demonstrate, even mission-critical mechanisms and maneuvers are subject to failure and require improvisation. We can anticipate that the initial asteroid-mining missions will be expensive, high-risk endeavors. That conclusion, and others that can be drawn from the technical details discussed above, should inform the selection of appropriate legal principles, as will be discussed forthwith.

II. WEIGHING THE LEGAL OPTIONS

There can be no economic argument for mining an asteroid unless one can exercise ownership over what one extracts. The current legal framework surrounding asteroids provides little reason for a prospective investor to conclude that his or her claim to asteroid resources would be honored or enforced, either under the domestic law of any nation with the appropriate infrastructure to support such an effort or under international treaties.[68] Various proposals for new le-

65. *Id.*

66. Richard Kerr, *Planetary Scientists Casting Doubt on Feasibility of Plan to Corral Asteroid*, 340 SCIENCE 668, 668–69 (2013), http://www.sciencemag.org/content/340/6133/668.full.

67. *Id.*

68. It is important, at this juncture, to distinguish the law of asteroids from the law of meteorites. As discussed in the Introduction, a meteorite is simply an asteroid that has touched down on the Earth's surface. In the United States, a meteorite that has fallen onto the surface is treated as property embedded in the Earth, and therefore belongs to the owner of the land on which it is found. Ritz v. Selma United Methodist Church, 467 N.W.2d 266, 269 (Iowa 1991); 1 AM. JUR. 2D *Abandoned, Lost, and Unclaimed Property* § 17, Westlaw (database updated Nov. 2015). A meteorite that falls on federal land comes within the administrative authority of the Department of the Interior, as the agency charged with the administration of the Antiquities Act, 16 U.S.C. §§ 431 et seq. (2006). *See, e.g.*, People of State of Cal. *ex rel.* Younger v. Mead, 618 F.2d 618, 621 (9th Cir. 1980).

This view prevails in the United Kingdom and in many Western countries and former gal paradigms have been made, each with its own strengths and weaknesses.

A. The Shortcomings of Existing Laws

Asteroids do not fall under any one country's jurisdiction,[69] and indeed spaceflight often involves collaboration between multiple countries, or citizens or corporations from various jurisdictions.[70] Thus, it is worth considering what international law might apply to an asteroid-mining endeavor, before turning to the domestic law of those countries most likely to be involved in such an effort.

1. International Law

Customary international law is not thought to include any principles directly applicable to asteroid mining.[71] Thus, if there are any relevant provisions of international law, they must originate in treaty sources. Of the five multilateral treaties applicable to outer space, two have potential legal implications for a transnational asteroid-mining industry. Neither, however, applies so clearly that one can conclude it would either authorize the extraction of resources from an asteroid or protect the legal rights of an entity that made such an extraction.

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colonies. D. G. Schmitt, *Law of Ownership and Control of Meteorites*, UNIV. SPACE RES. ASS'N, http://www.lpi.usra.edu/meetings/metsoc2001/pdf/5150.pdf (last visited Feb. 16, 2016). Nevertheless, practice varies substantially from one jurisdiction to the next; indeed, some countries, including Australia, India, Switzerland, and Denmark, have declared that all meteorites that fall within their respective territories are state property. *Id.*

As the discussion of the U.S. domestic law of asteroids in this Part will suggest, there is no reason to believe that a particular state's view on the legal status of asteroids will correspond to its treatment of meteorites. After all, the idea of assigning ownership on the basis of ownership of the locus of the meteorite's landfall would be hard to extend to asteroids, which exist in the *terra nullius* of outer space unless brought to Earth by artificial means.

69. Shackelford, *supra* note 13, at 141.

70. The International Space Station, for instance, is a collaboration between five space agencies. *International Cooperation*, NASA, http://www.nasa.gov/mission_pages/station/cooperation/index.html (last visited Feb. 16, 2016).

71. *See* Tina Hlimi, *The Next Frontier: An Overview of the Legal and Environmental Implications of Near-Earth Asteroid Mining*, 39 ANNALS AIR & SPACE L. 409, 442 (2014).

a. The Outer Space Treaty

The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), was opened for signature on January 27, 1967.[72] This treaty has been signed or ratified by over one hundred nations, including the United States and the Russian Federation.[73] It provides, in relevant part:

> 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. . . . States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty.[74]

The Outer Space Treaty's applicability to asteroids, however, has been called into serious question by numerous commentators. One line of criticism contends that "national appropriation" refers only to the assertion of *national* sovereignty over celestial bodies, and thus does not preclude private action.[75] Alternatively, it has been suggested that the prohibition on "national appropriation" forbids the appropriation of territory, but not of natural resources.[76] The diplo-

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72. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].

73. *Id.*

74. *Id.* at arts. II, VI.

75. For a small sampling of the literature on this point, see John Adolph, *The Recent Boom in Private Space Development and the Necessity of an International Framework Embracing Private Property Rights to Encourage Investment*, 40 INT'L L. 961, 964 (2006); Claudia Pastorius, *Law and Policy in the Space Industry's Global Lift-Off*, 19 BARRY L. REV. 201, 221 (2013); Davin Widgerow, *Boldly Going Where No Realtor Has Gone Before: The Law of Outer Space and a Proposal for a New Interplanetary Property Law System*, 28 WIS. INT'L L.J. 490, 501 (2010).

76. *See, e.g.*, Joanne Gabrynowicz, Written Testimony of Joanne Irene Gabrynowicz Before the Subcommittee on Space of the Committee on Science, Space, and Technology United States House of Representatives at 7 (Sept. 10, 2014), http://science.house.gov/sites/republicans.science.house.gov/files/documents/Gabrynowicz%20Final%20Testimony%20H.R.%205063.pdf. Professor Gabrynowicz points out that certain provisions of the Treaty contemplate the "exploitation of . . . natural resources" by space missions that fall

matic history of the Outer Space Treaty suggests that its drafters, seeking to prepare an agreement that could gain acceptance in both eastern and western blocs, deliberately chose to leave the possibility of private appropriation ambiguous.[77] Another line of criticism points out, "The term 'celestial body' has no firm legal definition. It is not certain whether 'celestial body' applies to all natural objects (including asteroids) or only to planets."[78]

b. The Moon Treaty

The other treaty of possible significance is the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, also known as the Moon Treaty.[79] The Moon Treaty has a number of provisions that would seem by their terms to clearly apply to asteroids. It provides, in relevant part:

> The provisions of this Agreement relating to the Moon shall also apply to other celestial bodies within the solar system, other than the earth, except in so far as specific legal norms enter into force with respect to any of these celestial bodies.[80]

As with the Outer Space Treaty, the interpretation of this treaty depends on the significance attached to the term "celestial bodies," a question that remains open to competing views. The Moon Agreement, however, can be read to implicitly include asteroids in that category. Article 1, Section 3 of the Moon Treaty provides, "This Agreement does not apply to extraterrestrial materials which reach the surface of the earth by natural means." The exception would seem unnecessary unless the Agreement applies to asteroids and comets that *have not* fallen to Earth; no other space objects could conceivably "reach the surface of the earth by natural means." If the

into its ambit. *Id.*

77. Pastorius, *supra* note 75, at 221–22; *see also* Ezra J. Reinstein, *Owning Outer Space*, 20 NW. J. INT'L L. & BUS. 59, 63 (1999) ("[T]he OST [Outer Space Treaty] is at best ambiguous, and at worst hostile, to the privatization and commercialization of space resources.").

78. Murnane, *supra* note 13, at 263–64; *see, e.g.*, Leslie I. Tennen, *Towards A New Regime for Exploitation of Outer Space Mineral Resources*, 88 NEB. L. REV. 794, 796–97 (2010) (observing that no "competent scientific body," including the International Astronomical Union, has defined the term "celestial body").

79. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, Dec. 18, 1979, 1363 U.N.T.S. 3 [hereinafter Moon Treaty].

80. *Id.* at art. 1.

treaty does apply to asteroids, what does that mean for resource extraction? Articles 4 and 11 establish legal principles that limit the use of any outer-space object under the treaty:

> Art. 4 § 1. The exploration and use of the moon shall be the province of all mankind and shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development. . . .
>
> Art. 11 § 1. The moon and its natural resources are the common heritage of mankind . . . .[81]

These provisions would subject asteroids to the conceptual regime of the "common heritage of mankind" (CHM), a category of international commons, over which all of humanity is putatively sovereign, that includes the high seas and Antarctica.[82] Prohibition of private exploitation is one of the central tenets of the CHM framework, as Articles 7 and 11 make clear:

> Art. 7 § 1. In exploring and using the moon, States Parties shall take measures to prevent the disruption of the existing balance of its environment . . . by introducing adverse changes in that environment . . . .
>
> Art. 11 § 2. The moon is not subject to national appropriation by any claim of sovereignty, by means of use or occupation, or by any other means.
>
> Art. 11 § 3. Neither the surface nor the subsurface of the moon, nor any part thereof or natural resources in place, shall become property of any State, international intergovernmental or non-governmental organization, national organization or non-governmental entity or of any natural person.[83]

These provisions unequivocally prohibit the extraction of natural resources from the celestial bodies within the ambit of the Moon Treaty, which, as the discussion of Article 1 suggests, likely includes asteroids.

The Moon Treaty, however, has been ratified or acceded to by fewer than twenty countries, none of them major space powers.[84] As

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81. *Id*. at arts. 4, 11.

82. Shackelford, *supra* note 13, at 110.

83. *Id*. at arts. 7, 11.

84. Outer Space Treaty, *supra* note 72. The only ratifying State Party of note is Kazakhstan, which is home to Russia's main spaceport, the Baikonur Cosmodrome. *Baikonur Cosmodrome*, NASA, http://www.nasa.gov/mission_pages/station/structure/

one noted space-law scholar remarks, "[T]he Moon Treaty . . . is a treaty that is already obsolete."[85]

c. The Other Space Treaties

The Outer Space Treaty and the Moon Treaty are often spoken of in conjunction with three other treaties that form the remainder of the corpus of international space law: the Rescue Agreement, the Liability Convention, and the Registration Agreement.[86]

i. The Rescue Agreement

The Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, commonly referred to as the Rescue Agreement, was opened for signature on April 22, 1968, and has been ratified by over one hundred states.[87] The Rescue Agreement establishes an international framework for organizing the safe recovery and return of astronauts or space vehicles that land outside the jurisdiction of the state to which they belong.[88] Presumably, this treaty would apply equally to asteroid-mining vehicles. Beyond that, the Rescue Agreement is of little relevance to the legal problems of asteroid mining.[89]

ii. The Liability Convention

The Convention on International Liability for Damage Caused by Space Objects, commonly referred to as the Liability Convention, was opened for signature on March 29, 1972, and has

elements/baikonur.html (last visited Feb. 15, 2016).

85. Glenn Harlan Reynolds, *International Space Law: Into the Twenty-First Century*, 25 VAND. J. TRANSNAT'L L. 225, 231 (1992).

86. *See, e.g.*, Adolph, *supra* note 75, at 963.

87. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, Apr. 22, 1968, 19 U.S.T. 7570, 672 U.N.T.S. 119.

88. *Id.*

89. *See* Adolph, *supra* note 75, at 966 ("[T]he Rescue Agreement has less importance than some other documents, especially the Outer Space Treaty, for the Rescue Agreement's 'broad mandate is not accompanied by any specific guidelines and is silent on such matters as which country would retain the financial obligation for such [a rescue] operation.'") (quoting Rosanna Sattler, *Transporting a Legal System for Property Rights: From the Earth to the Stars*, 6 CHI. J. INT'L L. 23, 29 (2005)).

been ratified by over seventy-five states.[90] The Liability Convention governs liability for damage caused by spacecraft launched by or from within a State Party; it provides for strict liability for accidents on the surface of the Earth or within the atmosphere, and a negligence-like standard for accidents "elsewhere than on the surface of the earth."[91]

The Liability Convention makes extensive provision for resolution of disputes through the appointment of a Claims Commission on a case-by-case basis.[92] Ultimately, however, the Claims Commission's decision is binding only by prior consent of the States Parties.[93] Thus, the Liability Convention essentially facilitates the consensual resolution of disputes between States Parties regarding outer space, nothing more.

The Liability Convention has been criticized for being largely devoid of substantive legal content, the outcome of a decade of strained negotiations between the United States and the Soviet Union over the accord.[94] One commentator remarks, "without a choice of law provision or codification of tort doctrines, the [Liability Convention] fails to provide the substantive rules that are necessary to resolve a space law dispute."[95] How, for instance, would a Claims Commission reconcile a dispute between a common law jurisdiction and a civil law jurisdiction, each with its own conception of "fault"?[96]

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90. Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187.

91. *Id*. at arts. II–IV. More precisely, liability attaches for outer space accidents "only if the damage is due to [the tortfeasor state's] fault or the fault of persons for whom it is responsible." *Id*. at art. III. Interestingly, Article VI, Section 2 of the treaty provides:

> No exoneration whatever shall be granted in cases where the damage has resulted from activities conducted by a launching State which are not in conformity with international law including, in particular, the Charter of the United Nations and the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies [i.e., the Outer Space Treaty].

Thus, if one reads the Outer Space Treaty to prohibit asteroid mining, strict liability, rather than fault-based liability, would seem to apply to mining operations as well.

92. *Id*. at arts. XIV–XX.

93. *Id.* at art. XIX § 2.

94. Marc S. Firestone, *Problems in the Resolution of Disputes Concerning Damage Caused in Outer Space*, 59 TUL. L. REV. 747, 753 (1985); *see also* Van C. Ernest, *Third Party Liability of the Private Space Industry: To Pay What No One Has Paid Before*, 41 CASE W. RES. L. REV. 503, 520 (1991).

95. Firestone, *supra* note 94, at 755.

96. *Id*. at 766.

These deficiencies may explain why, in nearly half a century of operation, the Liability Convention has never been invoked, despite several instances in which satellites reentered the atmosphere and crashed onto the surface of the Earth or into the ocean.[97] In the most significant example of damage caused by a space object, a Soviet satellite containing a radioactive power source crashed into the Canadian wilderness in 1978, spreading hazardous debris over an area of hundreds of thousands of square miles.[98] The joint U.S.-Canadian cleanup effort cost nearly $14 million Canadian dollars,[99] and although Canada sought only half of that cost from the Soviet Union under the Liability Convention, the vagueness of the treaty's substantive definition of "damages" gave the Soviet Union a basis to argue that it was not liable for even that reduced amount: for instance, it was contended that Canada had suffered no damages because the affected region was uninhabited.[100] Ultimately, "The conflict between the two countries finally was resolved[] primarily through diplomatic circumvention of the Liability Convention," and the Soviet Union paid only $3 million Canadian dollars.[101]

iii. The Registration Agreement

The Convention on Registration of Objects Launched into Outer Space came into force on September 15, 1976, and has been ratified by over sixty states.[102] It provides for a U.N.-operated registry of all objects launched into space, including technical data, to assist in the administration of the Outer Space Treaty, the Rescue Agreement, and the Liability Convention, as well as in the exploration of outer space generally.[103] As with the Rescue Agreement, it is reasonable to assume that this treaty would apply to asteroid-mining

97. Ernest, *supra* note 94, at 524.

98. *Id.* at 524–25.

99. This is about $39 million in 2016 U.S. dollars. *Inflation Calculator*, BANK OF CAN., http://www.bankofcanada.ca/rates/related/inflation-calculator/ (last visited Apr. 3, 2016); *Canadian Dollar-US Dollar Exchange Rate*, BLOOMBERG, http://www.bloomberg.com/quote/CADUSD:CUR (last visited Apr. 3, 2016).

100. Ernest, *supra* note 94, at 526. For another account of the incident and its aftermath, see generally Joseph A. Burke, *Convention on International Liability for Damage Caused by Space Objects: Definition and Determination of Damages After the Cosmos 954 Incident*, 8 FORDHAM INT'L L.J. 255 (1984).

101. Ernest, *supra* note 94, at 526.

102. Convention on Registration of Objects Launched into Outer Space, Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15.

103. *Id.* at pmbl.

ventures, but it does not supply any useful law.

2. Domestic Laws

a. The United States

i. Background Principles

To date, only one person has attempted to claim ownership of an asteroid under U.S. law: Gregory William Nemitz, who on November 3, 2003, filed a suit in federal court seeking declaratory judgment vesting in him title to the asteroid Eros.[104] Nemitz claimed that he had established a claim on Eros by virtue of two instruments: first, his registration of the asteroid in an unofficial database operated by the Archimedes Institute; and second, a financing statement he filed in California that listed him as both debtor and creditor and identified the asteroid as collateral.[105] Eros is the asteroid from whose surface NEAR Shoemaker made its extraordinary two-week broadcast in February 2001; Nemitz wanted NASA to pay him parking fees of twenty cents per year, plus late fees.[106]

On April 26, 2004, the U.S. District Court for the District of Nevada granted the United States' motion to dismiss for failure to state a claim.[107] The court dismissed Nemitz's claim on the basis that the plaintiff had failed to advance a cognizable legal theory by which he could argue that he had gained title to the asteroid, as neither the unofficial Archimedes registry nor an instrument under the California Commercial Code could create a property interest where there had previously been none.[108]

The court's rejection of Nemitz's claim—and, indeed, the arguments proffered by the government in its motion to dismiss—relies on the weakness of Nemitz's claim of right in Eros.[109] The court

104. Nemitz v. United States, No. CV-N030599-HDM-RAM, 2004 WL 3167042, at *1 (D. Nev. Apr. 26, 2004), *aff'd sub nom*. Nemitz v. NASA, 126 F. App'x 343 (9th Cir. 2005).

105. *Id.*

106. *Id.*; *see also* Complaint for Declaratory Judgement at 20, *Nemitz*, 2004 WL 3167042.

107. *Nemitz*, 2004 WL 3167042, at *2.

108. *Id.* at *1.

109. *Id.*; *see also* Defendants' Motion to Dismiss & Memorandum in Support Thereof at 9 n.4, *Nemitz*, 2004 WL 3167042 ("Because plaintiff has failed to show that he has a Constitutionally-protected property interest in Eros, this Court need not address plaintiff's contention that private ownership of an asteroid is permitted by Article II of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space,

omitted any discussion of how Nemitz's claim would have fared if, for instance, he had previously landed a spacecraft of his own on Eros.

In connection with Nemitz's zealous pursuit of his claim, however, both NASA and the State Department rendered administrative findings that suggested that, under the law as it then existed, even a more legitimate claim to ownership of an asteroid might fail. NASA, in a letter to Nemitz dated April 9, 2001, stated that "[an] individual claim of appropriation of a celestial body . . . appears to have no foundation in law," contrasting such claims on outer space resources with like claims over minerals in the deep seabed, for which there is specific statutory authority.[110] The State Department, in a letter dated August 15, 2003, took an even stronger position on the matter, writing, "In the view of the Department, private ownership of an asteroid is precluded by Article II of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies."[111]

ii. The U.S. Commercial Space Launch Competitiveness Act

In 2015, the legal framework for claims of property rights in asteroids changed dramatically with the passage of the U.S. Commercial Space Launch Competitiveness Act.[112] Title IV of the Act, the Space Resource Exploration and Utilization Act of 2015, established for the first time a basic framework for property rights in asteroids under U.S. law.[113]

Following some preliminary definitions, Title IV directs the President to "facilitate commercial exploration for and commercial recovery of space resources by United States citizens," "discourage government barriers" for commercial space exploration "consistent with the international obligations of the United States," and "promote

Including the Moon and Other Celestial Bodies.").

110. Complaint for Declaratory Judgement at exh. 2, *Nemitz*, 2004 WL 3167042. We can assume that the court here used the term "celestial body" inadvertently, and did not intend to thereby express an opinion as to whether that term, as used in the Outer Space Treaty and other authorities, includes asteroids. Nevertheless, the non-technical use of the term to refer to asteroids is an important consideration in interpreting the Outer Space Treaty.

111. *Id.* at exh. 1. Relevant international treaties are discussed *supra* Part II.A.1.

112. *See* U.S. Commercial Space Launch Competitiveness Act, Pub. L. No. 114-90, 129 Stat. 704 (2015).

113. *Id.* § 401.

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 . . . ."[114] He is to submit a report to Congress on the same within 180 days of enactment, or by May 23 of this year.[115]

Title IV's true legal effect, however, emerges in key substantive provisions: one aimed at domestic law, the other at international law. The first, captioned "Asteroid resource and space resource rights," establishes a property right in asteroid resources:

> A United States citizen engaged in commercial recovery of an asteroid resource or a space resource under this chapter shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law, including the international obligations of the United States.[116]

The second qualifies the right: "It is the sense of Congress that by the enactment of this Act, the United States does not thereby assert sovereignty or sovereign or exclusive rights or jurisdiction over, or the ownership of, any celestial body."[117]

What to make of these potentially contradictory provisions? We must consider at least four possibilities.

First, Congress has intentionally enacted a nullity, conveying a right in one provision and retracting it in another. This approach has its advantages. The drafters of Title IV may have decided that a strong domestic property right would sufficiently secure asteroid-mining efforts, at least for the time being, and that it was therefore not necessary to resolve the difficulties of international law at present. By disclaiming any assertion of sovereignty over asteroids, Congress may have sought to postpone an international debate that could discourage the development of a domestic space industry. Alternatively, Title IV may, like many seemingly contradictory or paradoxical enactments, reflect a rough compromise between competing legislative actors.[118]

114. *Id.* § 402.

115. *Id.*

116. *Id.*

117. *Id.* § 403.

118. *See, e.g.*, United Steelworkers of Am., AFL-CIO-CLC v. Weber, 443 U.S. 193, 217 (1979) ("Often we have difficulty interpreting statutes either because of imprecise drafting or because legislative compromises have produced genuine ambiguities.").

Second, Congress, through the two provisions reproduced, has implicitly expressed a view about the meaning of "celestial body."[119] In not so many words, Title IV suggests that the private extraction of resources from asteroids does not threaten the international norm against sovereignty over celestial bodies, because asteroids are not celestial bodies. It is worth noting that the term celestial body appears in only two other sections of the U.S. Code: once in reference to the official title of the Outer Space Treaty,[120] and once in a provision that implements certain obligations under the Outer Space Treaty by paraphrasing its language.[121] Therefore, one might well conclude that "celestial body" is a term of art in U.S. law, representing the category of objects to which the Outer Space Treaty will apply, and that Congress, by enacting Title IV, expresses its intention to exclude asteroids from that category and from the purview of the Outer Space Treaty altogether.

Third, Congress did not create a property right at all. Under this view, Title IV merely clarifies the application of domestic law to an international law problem; it does not resolve that problem. Observe that the domestic law provision contains an important qualification: that the property rights it creates are subject to the "international obligations of the United States."[122] Perhaps, then, the domestic provision tells asteroid prospectors, in effect, that if they can obtain a right to asteroid resources under international law, then the United States will honor it. *Nemitz* is overruled; nothing more.[123]

Fourth, Title IV expresses the drafters' view that U.S. sovereignty over a particular territory is not a prerequisite to granting property interests in resources extracted from that territory. U.S. law

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119. *See infra* Part II.B.1.

120. 18 U.S.C. § 7 (2001) (establishing federal jurisdiction over "[a]ny vehicle used or designed for flight or navigation in space and on the registry of the United States pursuant to the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies and the Convention on Registration of Objects Launched into Outer Space").

121. 51 U.S.C. § 70901 (2010) ("No civil space station authorized under section 103(a)(1) . . . may be used to carry or place in orbit any nuclear weapon or any other weapon of mass destruction, to install any such weapon on any celestial body, or to station any such weapon in space in any other manner."). The language mirrors Article IV of the Outer Space Treaty: "States Parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner." Outer Space Treaty, *supra* note 72.

122. U.S. Commercial Space Launch Competitiveness Act, Pub. L. No. 114-90 § 402, 129 Stat. 704 (2015).

123. *See supra* Part II.A.

applies to minerals or water removed from the asteroid, but not to the asteroid itself. As a matter of international law and legal theory, however, whether a state can grant property rights in *terra nullius*—territory over which no state is sovereign—remains an obscure and complicated question.[124]

Consider, for instance, the early twentieth-century dispute over the ownership of the Swan Islands in the Caribbean, which were at that time *terra nullius*.[125] In 1918, the State Department asked the Attorney General to determine the validity of the Swan Island Commercial Company's claim to ownership of the islands, which it asserted had arisen under the Guano Islands Act of 1856.[126] The Attorney General concluded that the company could have no such rights unless and until the U.S. government asserted sovereignty over the islands: "The property rights of said company, irrespective of the Guano Islands [A]ct, are dependent upon the assumption of sovereignty over the islands by the United States Government."[127]

To be sure, no authority appears to suggest that sovereignty is a prerequisite to property rights in resources *extracted* from *terra nullius*, as distinguished from rights in the territory itself. The Swan Island Commercial Company or its predecessors, for instance, had a right in the guano they harvested.[128] The high seas are outside the jurisdiction of any nation, yet national frameworks of property rights apply to resources extracted from those seas, such as fish.[129] When it comes to asteroids, however, such a distinction would seem semantic, or even metaphysical. Title IV defines "asteroid resource" to mean "a space resource found on or within a single asteroid," and "space resource" to mean "an abiotic resource in situ in outer space," including "water and minerals."[130] If an asteroid-mining enterprise ob-

124. *See* L. Benjamin Ederington, *Property as a Natural Institution: The Separation of Property from Sovereignty in International Law*, 13 AM. U. INT'L L. REV. 263, 274–75 (1997).

125. John W. Davis, Sovereignty over Swan Islands, 31 U.S. Op. Att'y Gen. 216, 220 (1918).

126. *Id.* at 216.

127. *Id.* at 223–24; *see also* Kingman Reef Atoll Dev., L.L.C. v. United States, 116 Fed. Cl. 708, 750–51 (2014) (discussing the Swan Islands opinion).

128. *See generally* Davis, *supra* note 125.

129. *See* RESTATEMENT (THIRD) OF THE FOREIGN RELATIONS LAW OF THE UNITED STATES § 521(b) cmts. a, e (AM. LAW INST. 1987); Robynne Boyd, *World Closes in on Consensus to Regulate Fishing on the High Seas*, SCI. AM. (Feb. 23, 2015), http://www.scientificamerican.com/article/world-closes-in-on-consensus-to-regulate-fishing-on-the-high-seas/.

130. U.S. Commercial Space Launch Competitiveness Act, Pub. L. No. 114-90 § 402, 129 Stat. 704 (2015).

tained control over a small asteroid in its entirety, with the intention of making use of all of its mineral content, would that be extraction of "asteroid resources" or assertion of exclusive rights over the territory?

The legislative history of Title IV sheds some light on this question without resolving the matter definitively. That history began with the legislative work conducted in connection with the American Space Technology for Exploring Resource Opportunities in Deep Space Act (ASTEROIDS Act), a similar bill introduced in the previous Congress by Representatives Bill Posey (R-FL) and Derek Kilmer (D-WA). That bill would have resolved conflicting claims to asteroid resources on a principle of "first in time, derived upon a reasonable basis, and in accordance with all existing international obligations of the United States."[131] It forbids harmful interference between spacecraft, with remedies at law and equity, and vested exclusive jurisdiction over asteroid law in the federal courts.[132]

The bill was referred to the House Committee on Space, Science, and Technology.[133] On September 10, 2014, the committee held a hearing on the bill, with testimony from five government and academic experts.[134] At that hearing, Dr. James F. Bell spoke on behalf of the Planetary Society, a substantial space advocacy and membership organization of which Bell is President.[135] He expressed the Planetary Society's ambivalence about the Act's language regarding property rights:

> The Society recognizes that a policy regarding property rights for resources mined from asteroids will eventually be important for commercial investment, but we believe that, since this is an area of current controversy among specialists, it is premature for us to take a position in support of the perspective on the property rights issues covered in the bill.[136]

131. H.R. 5063, 113th Cong. § 2 (2014).

132. *Id.*

133. *All Bill Information (Except Text) for H.R. 5063—ASTEROIDS Act,* LIBR. OF CONGRESS, https://www.congress.gov/bill/113th-congress/house-bill/5063/all-info#all-actions (last visited Feb. 21, 2016).

134. *Subcommittee on Space—Exploring Our Solar System: The ASTEROIDS Act as a Key Step*, COMMITTEE SCI. SPACE TECH. (Sept. 10, 2014), https://science.house.gov/legislation/hearings/subcommittee-space-exploring-our-solar-system-asteroids-act-key-step.

135. *Id.*

136. Statement by Dr. James F. Bell, President of the Planetary Society & Professor at Arizona State University Before the Subcomm. on Space, Comm. on Sci., Space, and Tech.,

Professor Joanne Gabrynowicz, also testifying at the hearing, criticized the Act as failing to "clearly identify which Federal agencies will be relevant to private sector asteroid resource exploration and utilization and the specific responsibility of each agency," among other technical flaws.[137] More significantly, Gabrynowicz pointed out:

> As with the ownership status of extracted resources, there is no legal clarity regarding the superior status of a claim found to be "first in time." World history is filled with examples of terrestrial land claims being perfected by making the first claim to a piece of land and then productively using it. No analogous claims have ever been made in space. Therefore the status of an intentionally asserted superior right to conduct specific commercial asteroid resource utilization activities is a question of first impression.[138]

She compared the problem of devising a principle of property rights in asteroids to the efforts to fairly allocate orbital positions for telecommunications satellites, which, she remarked, has resulted in a compromise between the principles of "first in time" and equity.[139]

There was no further action on the bill in the 113th Congress, perhaps because, as one news analysis puts it, "The act was seen less as a serious legal proposal than as an overture to the private sector."[140] Nevertheless, much of the language from the ASTEROIDS Act was inserted in the 2015 Space Launch Competitiveness Act when it was reported out from the House Committee on Space, Science, and Technology. Like the ASTEROIDS Act itself, that version of Title IV (then Title II) went further than the version ultimately signed into law, supplementing the basic declaration of a domestic

U.S. House of Rep. 7 (Sept. 10, 2014), http://science.house.gov/sites/republicans.science.house.gov/files/documents/HHRG-113-SY16-WState-JBell-20140910.pdf.

137. Gabrynowicz, *supra* note 76, at 1.

138. *Id.* at 9. Perhaps Gabrynowicz had in mind the foundational case of Johnson v. M'Intosh, 21 U.S. 543 (1823), where it was held that the English crown had originally obtained title to its colonial territories in North America by the principle of first in time and simultaneously excluded the Native American inhabitants of those territories from claiming superior title on the basis of their own prior discovery. As Chief Justice Marshall concluded, the English colonies had "a right to take possession, notwithstanding the occupancy of the natives, who were heathens, and, at the same time, admitting the prior title of any [other] Christian people who may have made a previous discovery." *Id.* at 576–77.

139. Gabrynowicz, *supra* note 76, at 9.

140. *All Bill Information (Except Text) for H.R. 5063—ASTEROIDS Act*, *supra* note 133; Blitzer, *supra* note 11.

property right with substantive rules. Subsection (b), "Safety of Operations," provided, "A United States commercial space resource utilization entity shall avoid causing harmful interference in outer space."[141] Subsection (c) created a civil cause of action for legal or equitable relief for harmful interference with asteroid mining.[142] Subsection (d), "Rule of Decision," directed the courts to find for the plaintiff in such an action if the plaintiff "(A) acted in accordance with all existing international obligations of the United States[] and (B) was first in time to conduct the activity," so long as "the activity [was] reasonable for the exploration and utilization of asteroid resources."[143]

The May 21, 2015, debate on the House floor gives a sense of the political forces that ultimately caused these provisions to be removed from the final bill. Representative Donna Edwards (D-MD), the ranking Democrat on the Subcommittee on Space,[144] rose in opposition to the bill, singling out the asteroid-resource provisions for special criticism: "[T]here is merit to positioning ourselves to answer questions associated with space mining, the property rights that accrue from such activities, and the harmonization with our treaty obligations. However, establishing prescriptive policies, as H.R. 2262 would do, is simply premature."[145] Representative Edwards pointed out that there had been neither interagency review nor subcommittee markup of the provisions in question.[146] She also noted concern from the administration regarding the issue of ensuring compliance with the Outer Space Treaty.[147]

Representative Edwards also entered into the record a letter from Professor Gabrynowicz, one of the experts who testified at the 2014 hearing. Gabrynowicz criticized the bill on the basis that, in her view, "[m]aking unextracted, in situ 'asteroid resources' subject to U.S. [f]ederal law" violates the Outer Space Treaty's prohibition on "national appropriation by claim of sovereignty, by means of use or

141. H.R. 2262, 114th Cong. § 202(a) (as engrossed by House, May 21, 2015).

142. *Id.*

143. *Id.*

144. *Biography*, CONGRESSWOMAN DONNA F. EDWARDS, http://donnaedwards.house.gov/index.php?option=com_content&view=article&id=412&Itemid=2 (last visited Dec. 31. 2015).

145. 126 CONG. REC. H3,512 (daily ed. May 21, 2015) (statement of Rep. Edwards).

146. *Id.*

147. *Id.*; *see also Statement of Administration Policy*, EXECUTIVE OFF. PRESIDENT (May 19, 2015), https://www.whitehouse.gov/sites/default/files/omb/legislative/sap/114/saphr2262r_20150519.pdf.

occupation, or by any other means."[148]

Representative Eddie Bernice Johnson (D-TX) criticized the bill on similar grounds: "I am not against asteroid mining or space resource utilization. Those activities will come in time. However, I am for getting any legislation that addresses these areas right. We are not at all close to resolving the many unanswered questions and issues concerning space resource utilization and property rights."[149] Representative Johnson cited the views expressed at the 2014 hearing in support of her contention that the question of property rights in asteroids had not been adequately studied.[150]

The bill was not amended in the House in response to these criticisms; it would be changed later in the Senate. Nevertheless, assuming that these views were in some way accommodated in order to ensure smooth passage through the Senate or to avoid a conference committee prior to final passage, they support the first reading of Title IV—that Congress postponed the resolution of the open question of property rights in asteroids in international law.

Further proceedings on the floor of the House, however, support the fourth proposed reading of the seeming contradiction in Title IV—that it reflects a distinction between extraction of resources, on the one hand, and annexation of territory, on the other. Along these lines, consider Representative Posey's floor statement in support of the bill, which included a letter from four legal scholars written in response to Professor Gabrynowicz's views[151]: "The bill does not grant U.S. jurisdiction to an asteroid or any asteroid resource. It does grant U.S. jurisdiction to companies that fall under U.S. jurisdiction . . . with the intent of adjudicating claims of 'harmful interference' between those companies if such allegations are made in the future."[152] On that basis, the academics contended, the bill was by no means inconsistent with the Outer Space Treaty.[153] More to the point, they argued that the bill does not deal with asteroids per se, only with resources after they have been "obtained"—that is, extract-

148. 126 CONG. REC. H3,513 (daily ed. May 21, 2015) (statement of Rep. Edwards).

149. *Id.* at H3,515 (statement of Rep. Johnson).

150. *Id.*

151. *Id.* at H3,518 (statement of Rep. Posey). The letter was co-signed by Henry R. Hertzfeld of the George Washington University; Matthew Schaefer of the University of Nebraska College of Law; James C. Bennett, a Space Fellow at the Economic Policy Centre in London; and Mark J. Sundahl of Cleveland–Marshall College of Law.

152. *Id.*

153. *Id.*

ed—from an asteroid[154]: "The use of the word 'in situ' in merely defining a space resource in the bill is not equivalent to claiming sovereignty or control over celestial bodies or portions of space."[155]

From this perspective, the sovereignty disclaimer in Title IV does not postpone an inevitable issue. Instead, it avoids an avoidable issue, because international law does not prohibit the extraction of resources from *terra nullius*.

No further legislative history appears in published records. The bill was passed by the House as reported out of committee, without further amendment to the provisions relating to asteroid law.[156] The bill reached its enacted form on the floor of the Senate, which adopted and passed an amended version put forward by Senator Cruz. The amendment was thus not debated or reported on by the Commerce, Science, and Transportation Committee, nor was it debated on the floor of the Senate.[157] When the bill returned to the House, the floor debate did not address changes to the asteroid-related provisions, and the Senate version was agreed to in short order, without amendment.[158] Speculation that the President would address the ambiguity with a signing statement[159] proved false.[160]

How, then, to decide what Congress meant by Title IV? Consider the industry's reaction to the bill's passage. Chris Lewicki, President of Planetary Resources, remarked that the Space Act "allows us to give assurances to our customers and investors as we build a resource business in space."[161] Megan Crawford, a senior official

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154. *Id.*

155. *Id*. Representative Posey also entered a second letter from Dennis J. Burnett, which enumerates examples of the treatment of rocks and soil recovered from the Moon as private property, in support of his contention that, as a matter of international custom, there already exists a property right in resources extracted from outer space. *Id.* at H3,519. This line of argument seems inapposite considering that the cases cited deal with government disposition of minimal scientific samples, rather than purely commercial use on a large scale.

156. *Id.*

157. 126 CONG. REC. S7,954 (daily ed. Nov. 10, 2015).

158. 126 CONG. REC. H8,185 (daily ed. Nov. 16, 2015).

159. Sarah Fecht, *Space Mining Bill Passes in Congress*, POPULAR SCI. (Nov. 17, 2015), http://www.popsci.com/congress-approves-space-mining-bill.

160. The President issued just one signing statement in 2015 on the National Defense Authorization Act for Fiscal Year 2016. *Presidential Signing Statements*, AM. PRESIDENCY PROJECT, http://www.presidency.ucsb.edu/signingstatements.php?year=2015 (last visited Dec. 31, 2015).

161. Luc Olinga, *New US Space Mining Law to Spark Interplanetary Gold Rush*, PHYS.ORG (Dec. 8, 2015), http://phys.org/news/2015-12-space-law-interplanetary-gold.html.

at Deep Space Industries, also remarked that Title IV was a "big win" because, with its passage, "[w]e don't have to work very hard to convince investors" of asteroid mining's legal viability.[162] Before the space-mining industry can hunt asteroids, it must first hunt for capital, and to that end a legal pronouncement of dubious effect is almost as good as one that is ironclad.

Viewed in that context, and in light of the legislative history, Title IV was most likely passed as a knowing, intentional contradiction—the first possibility discussed above. This conclusion also avoids the necessity of contending, under the fourth perspective, that Congress embedded into the law its perspective on a subtle, sophisticated question of property theory and *terra nullius*. Title IV solves the domestic law problem identified in *Nemitz*, but leaves the international law issue for future resolution after further study.

b. Other "Spacefaring" Nations

The United States aside, the Russian Federation is the nation with the most developed spacefaring capacities.[163] Two provisions of Russian law could potentially apply to asteroid-mining operations. First, Article 130 of the Civil Code of the Russian Federation provides, as a tautology, that the category of "immovable things," which are subject to state registration and regulation, includes "outer space objects," but only "if subject to state registration."[164]

Second, Decree No. 5663-1 of the Supreme Soviet of Russia[165] (About Space Activity) defines "space activity" to include, *inter alia*, "manufacturing of materials and other products in outer space."[166] The law establishes an administrative regime for licensing

162. *Id.*

163. For example, Russia currently operates the only space launch system capable of transporting crewmembers to and from the International Space Station. *See generally* Elizabeth Howell, *Roscosmos: Russia's Space Agency*, SPACE.COM (Sept. 9, 2013), http://www.space.com/22724-roscosmos.html.

164. GRAZHDANSKII KODEKS ROSSIISKOI FEDERATSII [GK RF] [Civil Code] art. 130. (Russ.), *translated in* CIVIL CODE OF THE RUSSIAN FEDERATION 63 (William E. Butler ed., 2002).

165. The Supreme Soviet was the former legislature of the Soviet Union and the nascent Russian Federation. *See generally* JOEL M. OSTROW, COMPARING POST-SOVIET LEGISLATURES: A THEORY OF INSTITUTIONAL DESIGN AND POLITICAL CONFLICT 29–92 (2000).

166. *Selected Examples of Laws Governing Space Activities: Russian Federation*, UNITED NATIONS OFF. FOR OUTER SPACE AFF., https://web.archive.org/web/20110810141236/http://www.unoosa.org/oosa/SpaceLaw/national/russian_federation/decree_5663-

outer space activities, and provides further that:

> The rights of jurisdiction and control over space objects, as well as of ownership thereof shall not affect the legal status of the area of outer space or the surface or subsoil of a celestial body occupied by it. In direct proximity to a space object of Russian Federation within the zone minimally necessary for ensuring safety of space activity, rules may be established that shall be binding for Russian and foreign organizations and citizens.[167]

At the very least, then, the Russian statutory language provides for a means of regulating asteroid mining. If one concludes that the term "celestial body" embraces asteroids, however, the law could be read as implicitly prohibiting the extraction of natural resources from asteroids, in that the law prohibits the establishment of ownership over "the surface or subsoil of a celestial body."[168] In any event, no prospector would wish to launch an enterprise on such an ambiguous and shaky legal foundation.

No other major spacefaring state's legal regime for outer space appears to include provisions addressing asteroid law.[169]

B. Proposals for a New Legal Regime

Commentators have made several proposals for a new legal

1_E.html (last visited Mar. 6, 2016).

167. *Id.* at art. 17 § 5.

168. *Id.*

169. *See generally Chinese Law: Registration, Launching and Licensing Space Objects*, 33 J. SPACE L. 437 (2007) (providing an unofficial translation of "Measures for the Administration of Registration of Objects Launched into Outer Space," promulgated by the National Defense Commission of Science, Technology, and Industry of China on February 8, 2001); *id.* at 442 (providing an unofficial translation of "Interim Measures on the Administration of Permits for Civil Space Launch Projects," promulgated by the National Defense Commission of Science, Technology, and Industry on November 21, 2002, effective December 21, 2002); *China's Space Activities (White Paper)*, CHINA NAT'L SPACE ADMIN. (Dec. 15, 2003), http://www.cnsa.gov.cn/n615709/n620681/n771967/69198.html; GOV'T OF JAPAN, STRATEGIC HEADQUARTERS FOR SPACE POLICY, BASIC PLAN ON SPACE POLICY (Jan. 25, 2013), http://www8.cao.go.jp/space/plan/plan-eng.pdf; SALIGRAM BHATT, INTERNATIONAL AVIATION AND OUTER SPACE LAW AND RELATIONS: REFLECTIONS ON FUTURE TRENDS (1996) (describing the space law of India); *Draft International Code of Conduct for Outer Space Activities*, EUR. EXTERNAL ACTION SERV. (Mar. 31, 2014), http://www.eeas.europa.eu/non-proliferation-and-disarmament/pdf/space_code_conduct_draft_vers_31-march-2014_en.pdf.

regime for asteroids. This Part outlines the alternatives proposed, before discussing the legal principles and empirical variables that should control the choice between the various options.

Two proposals for a law of asteroid mining envision the adoption of new international legal frameworks: one based on U.S. mining law, the other based on existing space treaties.

1. Based on U.S. Domestic Law

The recent spike of interest in extracting valuable metals from asteroids has invited comparison to the gold rush of nineteenth-century United States.[170] One scholarly work has suggested drawing directly on terrestrial mining law to govern the nascent industry. In her article, Lauren Shaw adapts the principles of influential U.S. gold-rush legislation to the space age.[171]

Essentially, the General Mining Law splits the acquisition of property rights in valuable mineral deposits into two phases: a prospector who finds a valuable deposit on public land stakes a claim by a relatively simple and inexpensive process, giving him a preliminary right to exclude others from the deposit.[172] The right persists so long as the prospector can demonstrate an annual investment of labor worth at least $100 in the plot.[173] Once the prospector has invested at least $500 worth of labor, he can apply for a "patent," essentially a deed in fee simple, in the land surrounding the mineral deposit.[174] The patenting process is inexpensive, and makes provision for public notice and adjudication of adverse claims.[175] The Act designates the

170. *See generally* Matthew Feinman, *Mining the Final Frontier: Keeping Earth's Asteroid Mining Ventures from Becoming the Next Gold Rush*, 14 PITT. J. TECH. L. & POL'Y 202 (2014). The industry seemingly embraces the comparison. *See The Space Economy: A Modern Day Gold Rush*, PLANETARY RESOURCES (Apr. 24, 2012), http://www.planetaryresources.com/2012/04/the-space-economy-a-modern-day-gold-rush-2/; Kirk Johnson, *A Start-Up Sees a Gold Rush Among the Stars*, N.Y. TIMES (Dec. 24, 2012), http://www.nytimes.com/2012/12/25/science/space/washington-company-is-working-to-mine-asteroids.html (profiling Planetary Resources).

171. *See generally* Lauren E. Shaw, *Asteroids, the New Western Frontier: Applying Principles of the General Mining Law of 1872 to Incentivize Asteroid Mining*, 78 J. AIR L. & COM. 121 (2013).

172. *See id.* at 147, 155.

173. *See* 30 U.S.C. § 28 (2007). A subsequent amendment permitted the payment of a USD 100 annual fee to the federal government in lieu of the investment of labor. 30 U.S.C.A. § 28f (West 2013); *see also* Shaw, *supra* note 171, at 159.

174. *See* 30 U.S.C.A § 29 (2015); Shaw, *supra* note 171, at 160.

175. *See* Shaw, *supra* note 171, at 161–62.

Bureau of Land Management (BLM) as the agency responsible for administering claims and patents.[176]

Shaw concedes that the General Mining Law may not be amenable to direct translation to a global industry.[177] First, the statutory scheme was built on a strong foundation of U.S. case law recognizing *pedis possessio*, a strong principle of desert-for-labor with regard to the extraction of mineral resources; not every jurisdiction emphasizes desert-for-labor in its property law and theory.[178] Second, no existing international tribunal exercises jurisdiction over adverse private-property claims in outer space; a global BLM would have to be brought into existence.[179]

Drawing inspiration from another nineteenth-century authority, Scott Shackelford argues for a system reminiscent of the Homestead Act of 1862.[180] The first investors to "arrive at a new resource area, occupy the territory, improve it, and equitably share some of the benefits" would be entitled to participate in an auction of the property rights—perhaps not in fee simple absolute, but in some sort of leasehold, with conditions of technology transfer to or direct sharing of profits with developing nations.[181] Not only would the leaseholds eventually terminate, but the system would also "award adverse possession in line with the labor theory of value."[182] Shackelford argues that this system would better balance the interests of private investors in the resources in question with those of the rest of mankind.[183]

2. Based on Extant Space Treaties

Matthew Feinman proposes a new treaty that would draw many of its provisions from the Outer Space Treaty, the Moon Treaty, and other treaties administered by the U.N. Office for Outer Space

176. *See* 30 U.S.C.A. § 29 (2015).

177. *See* Shaw, *supra* note 171, at 166.

178. *See id.*

179. *See id.* at 167.

180. *See* Shackelford, *supra* note 13, at 162 (discussing the Homestead Act, 12 Stat. 392 (1862) (repealed 1976)). It should be noted that Shackelford proposes this system to govern any number of regions that might be considered part of the common heritage of mankind, such as Antarctica, and not asteroids or outer space specifically. He does, however, use space exploration as the article's central case study.

181. Shackelford, *supra* note 13, at 164.

182. *Id.*

183. *See id.*

Affairs.[184]

Feinman's proposed treaty would avoid the pitfalls of the Outer Space Treaty by applying explicitly to asteroids and excluding them from the Outer Space Treaty's coverage. It would define asteroids explicitly as chattel, "moveable personal property that can be claimed by a single owner and held against other parties."[185] It provides that only an entity with "a physical presence on [an asteroid]" can make a claim on that body; thus, "a Party cannot stake a claim on an Asteroid while on Earth and maintain its superiority on the claim before arriving on site."[186] The States Parties to the treaty, however, agree to honor preliminary claims made by an entity attempting to reach an asteroid, so long as the preliminary claim is followed by the entity's actual physical presence within three months.[187]

Unlike the ASTEROIDS Act or the General Mining Law, Feinman's proposed treaty makes specific provisions to protect the asteroid's environment, Earth's environment, and asteroids that are of special scientific interest, the latter through the creation of "international scientific preserves" for additional international protection.[188]

Feinman's proposed treaty further provides that each State Party will bear liability directly for activities on an asteroid, including private activities carried out by its citizens.[189] Notably, while the treaty provides for the consensual resolution of disputes between states, and authorizes state parties to seek the assistance of the U.N. Secretary-General in achieving resolution, it makes no provision for mandatory enforcement.[190]

Ezra J. Reinstein outlines a similar system, in the form of an amendment to the Outer Space Treaty: a coordinating body, which Reinstein names the U.N. Space Exploration Registry, would approve private resource-extraction projects that meet scientific and technical criteria. The approved plan would then have priority over

184. *See generally* Feinman, *supra* note 170.

185. *Id.* at 224.

186. *Id.* at 225–26.

187. *Id.* at 226. A longer period might be appropriate; Planetary Resources' estimates indicate that it may take well over three months to reach many asteroids, even if the launch takes place immediately after the registration of plans. *Asteroid Targets of Interest*, INTERNET ARCHIVE WAYBACK MACHINE, https://web.archive.org/web/20150707075816/http://www.planetaryresources.com/asteroids/#asteroids-targets (last visited Apr. 12, 2016).

188. The language is drawn directly from the Moon Treaty. Feinman, *supra* note 170, at 226.

189. *Id.* at 230, 232.

190. *See id.* at 230–31.

any potentially conflicting plans, so long as it was executed within a given period of time.[191] The U.N. Space Exploration Registry would be empowered to consider environmental implications and the productivity of use in assigning or reassigning property rights on outer-space bodies.[192]

Finally, Andrew Tingkang proposes a radically simple alternative: treat all asteroids as chattel—that is, as movable property not capable of subdivision into parcels—and simply auction off the rights to each.[193]

III. Comparing the Possibilities

A. What Does a Good Solution Look Like?

As the various proposals discussed in Part II.B make clear, there is no single vision of what substantive or procedural components a law of asteroids should include. Nevertheless, it is possible to identify a set of interests that one could conclude, without fear of contradiction, should be reflected in any asteroid-mining legal framework.

1. It Encourages the Development of the Industry

Increasing the supply of platinum group metals will meaningfully improve the global standard of living, not to mention the economic prospects of anyone who has invested in such a venture and any jurisdiction that can tax the proceeds. Thus, the law should encourage asteroid mining operations to proceed. Broadly speaking, it could do so in two ways.

First, the law should encourage investment in asteroid mining by individualizing title. As suggested by the accounts of existing asteroid missions in Part I.C, the earliest asteroid-mining ventures are likely to be hazardous, high-risk, high-reward propositions. Tech-

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191. Reinstein, *supra* note 77, at 84–86.

192. *Id.* at 85, 88–93. For another proposal that delegates many of the sensitive questions to a proposed new international authority, see generally Lynn M. Fountain, Note, *Creating Momentum in Space: Ending the Paralysis Produced by the "Common Heritage of Mankind" Doctrine*, 35 CONN. L. REV. 1753 (2003).

193. Andrew Tingkang, Comment, *These Aren't the Asteroids You Are Looking for: Classifying Asteroids in Space As Chattels, Not Land*, 35 SEATTLE U. L. REV. 559, 586 (2012).

nical failures and miscalculations are bound to be common, as the experiences with Philae and Hayabusa indicate.[194] To the extent that the law can diminish or eliminate the legal risk of such an operation, it will encourage prospective investors to contemplate the substantial technical risks. It is now commonplace that privatization of ownership increases individual investment in each parcel by eliminating the phenomenon of the tragedy of the commons.[195] Thus, assigning individual title to some quantity of asteroid resources to a given venture, before the mission begins, seems an inevitable part of any solution, even though it does not need to be a freehold right.[196]

Second, the law should anticipate and prevent the countervailing problem of *too much* private ownership. Michael A. Heller developed the idea of the anticommons, a state of property relations in which property rights have become so fragmented, and so many participants possess a right to exclude one another, that the valuable uses of the property are diminished or rendered meaningless.[197] One can imagine an anticommons arising on a single asteroid if claims were so numerous that no single enterprise could exploit its claim effectively.

2. It Effects Global Adjudication of Claims and Liabilities

Asteroid mining necessarily implicates international law, as the *res* of the industry exists beyond the jurisdiction of any state.[198] Indeed, the Outer Space Treaty could be read to provide that no state sovereignty over asteroids is to be permitted.[199] Furthermore, recovery of mined resources may take place outside the launching jurisdiction, as was the case with Hayabusa,[200] or resources may be subject to competing extraction attempts based out of different jurisdictions.

194. *See supra* notes 48–62 and accompanying text.

195. For an influential account, see generally Robert C. Ellickson, *Property in Land*, 102 YALE L.J. 1315 (1993); Jared B. Taylor, Note, *Tragedy of the Space Commons: A Market Mechanism Solution to the Space Debris Problem*, 50 COLUM. J. TRANSNAT'L L. 254 (2011).

196. *But see* Hlimi, *supra* note 71, at 452 (suggesting a new treaty based on the U.N. Convention on the Law of the Sea, in which asteroid-mining enterprises would be in a position similar to fishermen on the high seas, owners of nothing ex ante but entitled to that which they can catch).

197. Michael A. Heller, *The Tragedy of the Anticommons: Property in the Transition from Marx to Markets*, 111 HARV. L. REV. 621, 668 (1998).

198. Shackelford, *supra* note 13, at 141.

199. *See supra* Part II.A.1.a.

200. *See supra* Part I.C.2.

In short, it is hard to imagine that domestic resolution of disputes will suffice, unless a particular domestic regime is so attractive that it becomes the de facto venue for asteroid-related disputes.

3. It Protects Environmental and Scientific Resources

As Ellickson suggests, privatization of title ensures that owners will internalize small- and medium-scale externalities, but often fails to effectively internalize large-scale externalities.[201] In the asteroid-mining context, such externalities can be thought of as those having effects on the Earth and those having effects on the asteroid. Space launches cause direct harms to the terrestrial atmosphere, as the rockets used for launch emit chemicals linked with the depletion of the ozone layer, such as hydrogen chloride.[202] Rocket launches have also been shown to deposit acidic chemicals on the land and water surrounding the launch site, reducing or changing the local populations of fish and vegetation,[203] and to cause short-term reduction of local air quality due to exhaust.[204] Rocket launches also pose risks that, although not made manifest upon each launch attempt, could produce damage in the aggregate given a sufficiently high number of launches. For instance, every launch of a nuclear-powered space vessel carries with it the risk that, if the launch should fail, radioactive debris could be scattered across surrounding areas.[205] This danger is not specific to asteroid mining, but increases in proportion to the overall number of launches of nuclear-powered vehicles. All the foregoing being said, there is also a countervailing case to be made for the terrestrial environmental *benefits* of asteroid mining, especially as efforts to extract rare earth metals prove increasingly threaten-

201. Ellickson, *supra* note 195, at 1334.

202. *See generally* Martin Ross et al., *Limits on the Space Launch Market Related to Stratospheric Ozone Depletion*, 7 ASTROPOLITICS 50 (2009); NASA, FINAL ENVIRONMENTAL IMPACT STATEMENT FOR THE MARS SCIENCE LABORATORY MISSION (Nov. 2006), http://science.nasa.gov/media/medialibrary/2010/11/05/MSL-FEIS_Vol1.pdf [hereinafter FINAL ENVIRONMENTAL IMPACT STATEMENT].

203. Thomas W. Dreschel & Carlton R. Hall, *Quantification of Hydrochloric Acid and Particulate Deposition Resulting from Space Shuttle Launches at John F. Kennedy Space Center, Florida, USA*, 14 ENVTL. MGMT. 501, 502 (1990).

204. FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 202.

205. Andrea Gini, *Safety of Nuclear Powered Missions*, SPACE SAFETY MAG. (Oct. 21, 2011), http://www.spacesafetymagazine.com/aerospace-engineering/nuclear-propulsion/plutonium-power-source-considered-choice-type-deep-space-missions-extraordinary-scientific-results-missions-voyager-pioneer-apollo-nuclear-power-yet-senate-appropriations-committee-decided-fund-ad/.

ing to sensitive ecosystems, such as the deep seabed.[206]

Asteroid-mining missions will also have implications for their target environments: the asteroids. In addition to environmental disruption caused by mining operations directly, some proposals for asteroid mining envision *in situ* processing of extracted materials, which would naturally increase the amount of pollution and debris left behind.[207] Other proposals suggest processing the material in low-Earth orbit, which raises questions about exacerbating an already-serious problem of near-Earth space debris.[208] Because human knowledge of those environments is much more limited, unnecessary harm to an outer-space environment may also be understood as a harm to scientific interests. For instance, in mid-November 2014, scientists at the ESA announced that Philae had discovered organic molecules on the surface of Comet 67P.[209] ESA researchers are still in the early phases of analyzing the data, but have already concluded that some of the molecules are of types never previously observed on a comet.[210] Had a mining craft without proper sterilization protocols touched down on the comet, thereby contaminating the comet's environment with organic material from Earth, the possibility of deriving

206. Hlimi, *supra* note 71, at 445.

207. Zacny et al., *supra* note 64, at 289 ("There are at least two exploitation options for mining asteroids: either an entire asteroid could be captured and brought back to the Earth's or Moon's vicinity, or the desirable resource could be extracted and processed in situ. Whether to bring an entire asteroid or to process resources *in situ*, will depend on the size of the target asteroid."); Werner Grandl & Akos Bazso, *Near Earth Asteroids—Prospection, Orbit Modification, Mining and Habitation*, *in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 415, 431 (Viorel Badescu ed., 2013) (envisioning *in situ* processing); Marco Cenzon & Dragoş Alexandru Păun, *Human Missions to NEO's—A System Perspective in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 168, 189 (Viorel Badescu ed., 2013) ("Assuming available a sufficient amount of power (e.g. nuclear reactor), processing on site the material will increase the percentage of valuable resources within the returning mass. In first approximation a longer mining/processing period could raise the payback mass ratio."); *see also* LEWIS, *supra* note 19, at 103 (envisioning in situ production of fuel from water extracted from the asteroid).

208. Grandl & Bazso, *supra* note 207, at 436; *see* Taylor, *supra* note 195 (on space debris). Interestingly, the Moon is not commonly discussed as a site for processing natural resources extracted from asteroids; in part, the Moon, like the Earth, is a gravity well, from which it takes a relatively large quantity of energy to escape. Didier Massonnet, *Asteroid Capture*, *in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 459, 465 (Viorel Badescu ed., 2013).

209. Sarah Fecht, *Philae Discovers Organic Molecules on a Comet*, POPULAR SCI. (Nov. 19, 2014), http://www.popsci.com/philae-finds-organic-molecules-comet.

210. *Organic Molecules on Comets: Philae's First Results from Churi Prove Surprising*, SCI. DAILY (July 30, 2015), https://www.sciencedaily.com/releases/2015/07/150730172518.htm.

scientific knowledge from the asteroid would have been forever lost.[211]

Finally, and most broadly, there may be a more profound moral concern. In recent decades, men and women from around the globe have come to profoundly regret the choices of previous generations to consume Earth's natural resources in ways that have left lasting scars.[212] Any legal framework erected today should consider the contingent remainder interests of all the unborn generations to come. Moreover, our first steps in appropriating extraterrestrial resources will set the precedent for every step to follow. Should we be uncritical of our property entitlement to the universe? Even if humankind as a species concludes that the whole solar system is ours, by virtue of being the only sentient beings herein,[213] where do we draw the line?

Feinman and Reinstein's plans, among others, both incorporate environmental protection components in their respective regulatory schemes.[214] The questions linger, however, to what extent will it be possible to anticipate which actions could harm such alien environments and how to give standing to every person, present and future, whose rights will be affected.

B. What Empirical Factors Might Influence a Good Solution?

The most useful solutions to the problems of asteroid law will promote the policy ends outlined above. Most of the proposals discussed in Part III.A already do, to one extent or another. How, then,

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211. In fact, the NASA Office of Planetary Protection regulates all NASA missions to other bodies in the solar system in order to prevent unintentional contamination. Its motto is "All of the planets, all of the time." *Office of Planetary Protection*, NASA, http://planetaryprotection.nasa.gov/methods (last visited Feb. 15, 2016). The Office classifies some asteroids in Category I, requiring no sterilization protocols, but other asteroids and all comets in Category II, involving sterilization planning and implementation. The scale goes up to Category V. *Mission Categories*, NASA, http://planetaryprotection.nasa.gov/categories (last visited Feb. 15, 2016).

212. *See generally* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014 SYNTHESIS REPORT (2015), http://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf.

213. *See, e.g.*, Robert Krulwich, *Is There a Giant Life Form Lurking in Our Solar System? Possibly, Say Scientists*, NPR (Aug. 14, 2013, 11:13 AM), http://www.npr.org/blogs/krulwich/2013/08/14/211945779/is-there-a-giant-life-form-lurking-in-our-solar-system-possibly-say-scientists (discussing the possibility of non-sentient life elsewhere in the solar system).

214. Feinman, *supra* note 170, at 228; Reinstein, *supra* note 77, at 73.

to choose between the many possible frameworks? To some extent, which legal principles will be most effective and equitable depends on at least two disputed or unknown empirical variables.

1. How Many Asteroids Are Viable Candidates?

Determining whether the pie is large or small has implications for which legal framework is most appropriate. To the extent that the scientific question remains unresolved, the legal questions must remain open as well.

If there are many asteroids that would make good candidates for mining, then there is less need to conserve them; the legal framework should, accordingly, emphasize security of investment by granting title to asteroids far in advance.[215] The law does not need to insist upon desert-for-labor, as required in Shaw's and Shackelford's proposals, nor upon a reasonable-capture principle, as in Feinman's suggestion.[216] Tingkang's proposal for an open auction of rights in asteroids might, under such circumstances, make good sense.[217]

More to the point, if candidate asteroids are plentiful, there is little need to divide up any but the largest of them[218] between multiple owners; better to grant each owner rights to the whole of the body, perhaps limited in time, to avoid the possibility of interference between multiple efforts. Again, Tingkang's suggestion that asteroids should be treated as chattel, rather than as land capable of subdivision, would seem a productive one—perhaps tempered by a maximum diameter for chattel asteroids, so that one cannot, say, acquire title to an entire dwarf planet.[219]

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215. It bears repeating that the concern here is with the asteroid mining of the near future; as any economy matures and grows larger, the system of property entitlements will necessarily change. *See* Harold Demsetz, *Toward a Theory of Property Rights*, 57 AM. ECON. REV. 347, 350 (1967).

216. Shaw, *supra* note 171, at 159; Shackelford, *supra* note 13, at 162; Feinman, *supra* note 170, at 225–26.

217. Tingkang, *supra* note 193, at 586. Some limiting factor, tied to the industry's actual capacity to mine the asteroids, would need to be conceived of, but it could be much looser than a strict requirement of useful possession.

218. The largest bodies will inevitably have to be excluded from any regime that treats asteroids as chattel, lest the "dwarf planets"—bodies as large as 600 miles across—become the possessions of whomever sets foot on them first. *See Pluto and the Developing Landscape of Our Solar System*, INT'L ASTRONOMICAL UNION, https://www.iau.org/public/themes/pluto (last visited Feb. 25, 2016) (evidencing ambiguity about whether the category of asteroids includes dwarf planets).

219. *Id.*

On the other hand, if candidate asteroids are few in number, it seems foolish to divide them up so arbitrarily. As the account of past missions in Part I makes clear, humankind has yet to return more than dust particles from an asteroid; it is reasonable to expect that the initial asteroid-mining missions will make use of only a small part of the target body's mass. Therefore, it would be *unreasonable* to assign property rights in whole asteroids—that is, to treat them as chattel. Instead, each asteroid mining operation might only be entitled to legal possession of whatever portion of an asteroid it could reasonably expect to capture, perhaps under a flexible claim system like the ones proposed by Shackelford, Shaw, Feinman, or Reinstein.[220]

By the same reasoning, the fewer the number of candidate asteroids, the greater the risk of conflicts between asteroid-mining programs, and the greater the need for strong liability mechanisms in the case of intentional or accidental interference.

So—which is it? Many or few? It is surprisingly hard to say, even though there are millions of asteroids orbiting the sun.[221] The first limiting factor, as discussed in the Introduction, is that there are many types of asteroids. Only a small portion are M-class asteroids, rich in valuable metals.[222] Estimates suggest that M-class asteroids only make up nine to ten percent of the asteroid population.[223]

As a second limiting factor, not all asteroids are equally accessible. The vast majority of asteroids in the solar system orbit the sun between Mars and Jupiter, as part of the main asteroid belt, or share Jupiter's orbit.[224] Reaching these would be quite time-consuming and expensive, to say nothing of hauling back any substantial quantity of material.[225] Instead, scientists and entrepreneurs

220. Shaw, *supra* note 171, at 159; Shackelford, *supra* note 13, at 162; Feinman, *supra* note 170, at 225–26; Reinstein, *supra* note 77, at 84–86.

221. *Asteroids: Read More*, *supra* note 15.

222. David J. Tholen & M. Antonietta Barucci, *Asteroid Taxonomy*, *in* ASTEROIDS II 298, 309–12 (Richard P. Binzel et al. eds., 1989). As the presence, distribution, and usefulness of "volatiles" in asteroids are more speculative, they are left to the side for the purposes of this discussion.

223. *Id.* at 312; Joan-Pau Sanchez & Colin R. McInnes, *Available Asteroid Resources in the Earth's Neighbourhood*, *in* ASTEROIDS: PROSPECTIVE ENERGY AND MATERIAL RESOURCES 439, 454 (Viorel Badescu ed., 2013). Notably, at least one scientist argues that there is enough metal in the rocky asteroids of other classes to justify resource extraction. *See* LEWIS, *supra* note 19, at 113–14.

224. *Our Solar System 2013*, NASA, https://www.nasa.gov/sites/default/files/files/Solar_System_Lithograph_Set_h.pdf (last visited Feb. 25, 2016).

225. JOHN BROPHY ET AL., ASTEROID RETRIEVAL FEASIBILITY STUDY 6 (Apr. 2, 2012), http://www.kiss.caltech.edu/study/asteroid/asteroid_final_report.pdf (indicating that only a near-Earth asteroid could be successfully returned to the vicinity of Earth).

have focused on near-Earth asteroids, a much smaller group of bodies that have split off from the asteroid belt and entered into an orbit around the sun that brings them, at least from time to time, into Earth's vicinity.[226] Astronomers have identified about 13,500 near-Earth asteroids so far.[227]

By this logic, there are about 1,000 M-class asteroids on orbits that bring them close to Earth. Other estimates, however, diverge widely. DSI, in its marketing materials, speaks in terms of "[m]ore than two million near Earth asteroids ('NEAs') . . . in orbits roughly similar to that of Earth."[228] Perhaps DSI hopes to mine smaller asteroids that have not yet been discovered; scientists, however, point out that evaluating a newly discovered asteroid for mission suitability can be a very difficult proposition, as an asteroid whose orbit crosses Earth's will only remain within range of telescopes and other observational equipment for a few days before disappearing again.[229] At the other extreme, Planetary Resources has identified eight asteroids that it sees as viable targets for the near term.[230] NASA, making some rough assumptions, categorizes thirty-nine near-Earth objects as accessible targets for a manned mission, which is more in line with Planetary Resources' assessment than DSI's.[231]

Further research into more precise criteria to distinguish between viable and non-viable targets for asteroid mining will help to resolve the factual question and, thus, the legal one. For now, we are left with a choice somewhere between two million and eight.

2. How Big Will the Target Asteroid Be?

"Asteroids range in size from Ceres—the largest at about 950 kilometers (590 miles) in diameter and also identified as a dwarf

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226. *Id.*

227. *Near-Earth Asteroid Discovery Statistics*, NASA, http://neo.jpl.nasa.gov/stats (last visited Feb. 4, 2016).

228. *Prospecting for Space Resources*, *supra* note 30.

229. *See generally* Kerr, *supra* note 66.

230. *Targets of Interest*, *supra* note 27.

231. *Near-Earth Object Human Space Flight Accessible Targets Study (NHATS)*, NASA, http://neo.jpl.nasa.gov/cgi-bin/nhats (last visited Feb. 25, 2016). This is not to suggest that an asteroid-mining mission would necessarily or even likely involve a human crew. Nevertheless, like a crewed mission, a mining operation would have to target an asteroid from which it is possible to make a safe return to Earth. Therefore, we can expect that some of the targets would overlap.

planet—to bodies that are less than 1 kilometer (0.6 mile) across."[232] The real question, then, is what size bodies will the asteroid miners target?

As above, the answer to that question has significant legal implications. The smaller a target asteroid, the more reasonable it would be to treat it as chattel, because there is less opportunity for efficient use by a second mining enterprise. The less likely the same body will be targeted by multiple operations, the lesser the need for strong liability rules for interference *in situ*. On the other hand, a small body may be especially difficult to study from Earth, meaning that setting out a full mission plan may not be feasible prior to reaching the asteroid and subjecting it to study on site.[233] The ESA, for instance, could not select a landing site for Philae until Rosetta had reached 67P and photographed its surface; even then, the "relatively short" process of deciding where to touch down required six weeks of preparation.[234]

Thus, fully evaluating the feasibility, useful value, and potential externalities of an asteroid-mining mission may not be possible until that mission is well underway. Detailed registration of specific plans with regulatory bodies prior to launch, as envisioned in some of the proposals in Part II.B, may be too burdensome for missions to asteroids, whose precise features cannot be known with certainty ex ante. This is true for all asteroids, large and small, but especially true for small, relatively unstudied bodies.[235]

As in the case of the number of targets, whether the asteroids will be large or small remains to be seen. Planetary Resources' eight preliminary targets are all fairly small; the smallest is thought to be forty to ninety meters across and the largest 840 to 900 meters across.[236] The NASA plan to haul an asteroid close enough to Earth for astronauts to visit the asteroid involves finding a target asteroid on the order of 100 meters across; success in that endeavor might

232. *Our Solar System 2013*, *supra* note 224. In fact, the lower bound is strictly semantic; the solar system is full of asteroid-like bodies as small as pebbles, but once they are sufficiently small, they are referred to as meteorites. *Meteors & Meteorites: Overview*, NASA, http://solarsystem.nasa.gov/planets/meteors (last visited Feb. 25, 2016).

233. *See* Kerr, *supra* note 66.

234. *Selecting a Landing Site for Rosetta's Lander, Philae*, EUR. SPACE AGENCY (Nov. 8, 2014), http://sci.esa.int/rosetta/54468-selecting-a-landing-site-for-rosettas-lander-philae.

235. Any proposal that involves preapproval of asteroid missions by a regulatory body, such as Reinstein's, should account for these uncertainties. Reinstein, *supra* note 77, at 84–86.

236. *Asteroid Targets of Interest*, *supra* note 187.

shape future asteroid-mining plans.[237] Lewis, on the other hand, has contemplated targets kilometers wide.[238]

To some extent, the ideal size is dependent on the precise mission design; larger asteroids exert a stronger gravitational pull,[239] which may make landing on the body easier, but will require more fuel to depart.[240] Further development of specific asteroid-mining plans may be necessary before this question can be fully resolved.

3. Further Questions

Some questions simply cannot be resolved without further experience. For instance, how often will the early missions tend to fail? A legal regime can compensate for particularly risky activities by awarding property rights more expansively, requiring a lesser demonstration of labor before awarding property entitlements or eliminating the requirement of reasonable likelihood of capture. Previous missions have already experienced serious errors and flaws, but until more efforts have been made, it will not be possible to answer this question definitively. Other questions, while capable of resolution at present, are beyond the scope of this Note. For instance, what is the likelihood that the major spacefaring nations would agree to a new treaty for space? Writing in early 2016, it seems unlikely that the United States and the Russian Federation would consent to any new scheme of mandatory adjudication between their citizens by an international body. If that casual empirical assessment is borne out, in what other ways might a global law of asteroids be fashioned—reciprocal domestic arrangements? New interpretations of existing treaties?

CONCLUSION—PROBLEM, POLITICS, AND POLICY

John W. Kingdon has developed a “three streams” model of

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237. The NASA mission is discussed *supra* notes 64–67 and accompanying text.

238. *See* LEWIS, *supra* note 19, at 111–12 (using Amun, a two-kilometer wide asteroid, as a hypothetical target).

239. *See, e.g.*, *Newton’s Law of Universal Gravitation*, ENCYCLOPEDIA BRITANNICA ONLINE, http://www.britannica.com/science/Newtons-law-of-gravitation (last visited Feb. 25, 2016) (summarizing Sir Isaac Newton’s universal law of gravitation, which holds that the gravitational pull between two objects is a function of their masses).

240. *See* LEWIS, *supra* note 19, at 123 (discussing missions to near-Earth asteroids in terms of “delta V,” or the total acceleration against gravity, required to reach them and depart).

political change, in which he argues that the decision makers' acknowledgement of a problem, the development of appropriate circumstances of politics, and the availability of applicable policy solutions are the outcomes of independent processes.[241] Only when the three "streams"—problem, politics, and policy—merge at one time is a decision likely to be made.[242]

For the time being, asteroid law is full of policy alternatives. There may even be the political will to spur the development of the industry. That said, until the problem presents itself fully—perhaps not until some enterprise has its figurative hands on the asteroid and wants to bring the fruits of its venture back to Earth—further legal development is unlikely. Any proposal for asteroid law, and any proposal for the law of a world that has not yet come into being, should be informed by as detailed as possible a conception of what that future day will be like. For now, "It is the uncrossed desert and the unclimbed ridge. It is the star that is not reached and the harvest sleeping in the unplowed ground. . . . [W]e will bend it to the hopes [o]f man."[243]

*Samuel Roth**

241. JOHN W. KINGDON, AGENDAS, ALTERNATIVES, AND PUBLIC POLICIES 86–89 (1995).

242. *Id.* at 165–66.

243. Lyndon Baines Johnson, *The President's Inaugural Address*, AM. PRESIDENCY PROJECT (Jan. 20, 1965), http://www.presidency.ucsb.edu/ws/?pid=26985.

* Head Solicitations Editor, *Columbia Journal of Transnational Law*; J.D. Candidate, Columbia Law School, Class of 2016. The author would like to thank Professor Michael Gerrard for his invaluable assistance and feedback. Thanks also to Brendan Cohen and Sean C. Solomon for their commentary and advice, and to Helena Roth, best of wives.