ICE & STONE 2020

WEEK 12: MARCH 15-21, 2020

Presented by The Earthrise Institute

#12

Authored by Alan Hale

THE EARTHRISE INSTITUTE

Simply stated, the mission of the Earthrise Institute is to use astronomy, space, and other related endeavors as a tool for breaking down international and intercultural barriers, and for bringing humanity together. The Earthrise Institute took its name from the images of Earth taken from lunar orbit by the Apollo astronauts. These images, which have captivated people from around the planet, show our Earth as one small, beautiful jewel in space, completely absent of any arbitrary political divisions or boundaries. They have provided new inspiration to protect what is right now the only home we have, and they encourage us to treat the other human beings who live on this planet as fellow residents and citizens of that home. They show, moreover, that we are all in this together, and that anything we do involves all of us.

In that spirit, the Earthrise Institute has sought to preserve and enhance the ideals contained within the Earthrise images via a variety of activities. It is developing educational programs and curricula that utilize astronomical and space-related topics to teach younger generations and to lay the foundations so that they are in a position to create a positive future for humanity.

ALAN HALE

Alan Hale began working at the Jet Propulsion Laboratory in Pasadena, California, as an engineering contractor for the Deep Space Network in 1983. While at JPL he was involved with several spacecraft projects, most notably the Voyager 2 encounter with the planet Uranus in 1986. Hale eventually left JPL and returned to New Mexico where he earned his Ph.D. in 1992 with a thesis entitled "Orbital Coplanarity in Solar-Type Binary Systems: Implications for Planetary System Formation and Detection" which was published in the January 1994 issue of the Astronomical Journal), and which has since become one of the seminal papers in early exoplanet research, with over 200 citations to date.

Alan Hale's research interests include the search for planets beyond the solar system, including those which might have favorable environments for life; stars like the sun; minor bodies in the solar system, especially comets and near-Earth asteroids; and advocacy of spaceflight. He is primarily known for his work with comets, which has included his discovery of Comet Hale-Bopp in 1995. In recent years he has worked to increase scientific collaboration between the U.S. and other nations.

He is an outspoken advocate for improved scientific literacy in our society, for better career opportunities for scientists, and for taking individual responsibility to make ours a better society. He has been a frequent public speaker on astronomy, space, and other scientific issues He has been involved with the Icarus Interstellar project and served on the Advisory Board for Deep Space Industries.

Alan Hale lives in the Sacramento Mountains outside of Cloudcroft, New Mexico with his partner Vickie Moseley. He has two sons, Zachary and Tyler, both of whom have graduated from college and are now pursuing their respective careers. On clear nights he can often be found making observations of the latest comets or other astronomical phenomena.

COVER IMAGES CREDITS:

Front cover: Three impact craters of different sizes, arranged in the shape of a snowman, make up one of the most striking features on Vesta, as seen in this view from NASA's Dawn mission. In this view the three "snowballs" are upside down, so that the shadows make the features easily recognizable. North is to the lower right in the image, which has a resolution of 230 feet (70 meters) per pixel The image is composed of many individual photographs taken between October and December 2011 by Dawn's framing camera. The largest of the three craters, Marcia, has a diameter of about 40 miles (60 kilometers). Courtesy NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Back cover: This enhanced-color view from NASA's Dawn mission was imaged on September 20, 2012. It shows an unusual 'pitted terrain' on the floors of the crater named Cornelia on the giant asteroid Vesta. Courtesy NASA/JPL-Caltech/UCLA/MPS/DLR/IDA/JHUAPL

THIS WEEK IN HISTORY

MARCH **15** | 16 | 17 | 18 | 19 | 20 | 21

MARCH 15, 2020: Comet ATLAS C/2019 Y1 will pass through perihelion at a heliocentric distance of 0.838 AU. This is the fourth known member of a "group" of comets, the first of which appeared in 1988; this, and other comet "groups," are discussed in a future "Special Topics" presentation. Comet ATLAS has become bright enough for visual observations, and current information about it is covered at the Comet Resource Center.

MARCH 15, 2032: The short-period Comet 252P/LINEAR will pass by Earth at a distance of 0.058 AU. This comet passed slightly closer to Earth in 2016 and, based upon its brightness then, may reach 6th magnitude during this approach. Forthcoming close approaches of comets to Earth are discussed in a future "Special Topics" presentation.

15 | MARCH **16** | 17 | 18 | 19 | 20 | 21

MARCH 16, 1983: Robert Clayton and Toshiko Mayeda at the University of Chicago announce that analysis of the meteorite ALH A81005, found in Antarctica the previous year, has an isotopic composition very similar to that of lunar rocks returned by the Apollo astronauts. ALH A81005 accordingly becomes the first-known lunar meteorite found on Earth.

Allan Hills A81005, a lunar meteorite discovered in the Transantartctic Mountains. Courtesy NASA.

15 16 MARCH 17 18 19 20 21

MARCH 17, 1852: The Italian astronomer Annibale de Gasparis discovers the large main-belt asteroid now known as (16) Psyche. Psyche is one of the most massive asteroids in the main belt and is composed primarily of iron, nickel, and other metals; it may possibly be the remnant core of a protoplanet. It is the destination of NASA's forthcoming Psyche mission – to be covered in a future "Special Topics" presentation – and conceivably could be a source for future mining operations, the subject of this week's "Special Topics" presentation.

MARCH 17, 1899: American astronomer William Pickering discovers Saturn's 9th moon, Phoebe, on photographs that had been taken the previous August. Phoebe, one of the "outer" moons of Saturn, was the first planetary moon to be discovered photographically.

MARCH 17, 2013: A NASA monitoring program detects the largest "real-time" impact on the lunar surface, by an object with an estimated mass of 40 kg. Lunar impacts are discussed in a future "Special Topics" presentation.

MARCH 17, 2015: David Tholen, Scott Sheppard, and Chad Trujillo detect a short tail accompanying the main-belt asteroid (493) Griseldis in images obtained with the 8.2-meter Subaru Telescope at Mauna Kea Observatory in Hawaii. The tail is likely the result of an impact by a smaller object, and meanwhile makes Griseldis one of the known "active asteroids," which are discussed in a future "Special Topics" presentation.

MARCH 17, 2020: The main-belt asteroid (2734) Hasek will occult the 7th-magnitude star HD 71866 in Lynx (also designated as TZ Lyncis). The predicted path of the occultation is from north to south from far northern Greenland, through central Canada, the central U.S., and north-central Mexico.

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MARCH 18, 2002: Comet 153P/Ikeya-Zhang P/2002 C1 passes through perihelion at a heliocentric distance of 0.507 AU. The comet was moderately conspicuous to the unaided eye and was found to be identical to a comet observed in 1661 by Johannes Hevelius, and becomes the comet with the longest orbital period to be definitely seen on two returns. It is a future "Comet of the Week."

***THERE ARE NO CALENDAR ENTRIES FOR MARCH 19.**

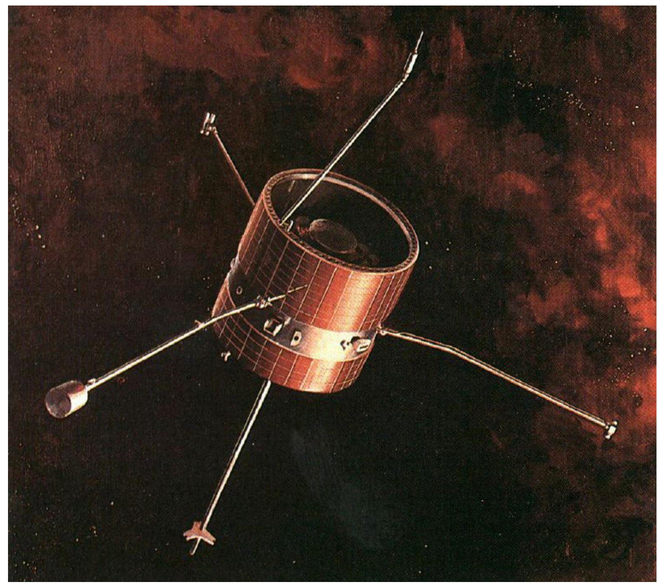
15 16 17 18 19 MARCH 20 21

MARCH 20, 1066: Comet 1P/Halley passes through perihelion at a heliocentric distance of 0.574 AU. The comet was especially prominent during that return, in part because of an approach to Earth of 0.104 AU in late April, and is featured in the Bayeux Tapestry commemorating the Battle of Hastings, and also apparently in Native American petroglyphs in Chaco Canyon, New Mexico. This and other returns of Comet Halley are discussed in last week's "Special Topics" presentation.

MARCH 20, 1970: Comet Bennett 1969i passes through perihelion at a heliocentric distance of 0.538 AU. Comet Bennett – the second comet I ever observed – was one of the "Great Comets" of the latter 20th Century and was the second comet ever to be observed from space; it is a future "Comet of the Week."

MARCH 20, 1986: NASA's Pioneer 7 spacecraft, originally launched into a heliocentric orbit in August 1966, passes 0.08 AU from Comet 1P/Halley, and is able to perform measurements of interactions between the comet's ion tail and the solar wind. The various spacecraft encounters with Comet Halley in 1986 are discussed in last week's "Comet of the Week" presentation.

MARCH 20, 2020: The main-belt asteroid (1574) Meyer will occult the 4th-magnitude star 45 Arietis. The predicted path of the occultation crosses south-central Russia and northeastern China.



Artist's conception of Pioneer 7. Courtesy NASA.

15 16 17 18 19 20 MARCH 21

MARCH 21, 2016: The short-period Comet 252P/LINEAR passes 0.036 AU from Earth, the second-closest cometary approach to Earth thus far in the 21st Century, reaching 5th magnitude in the process. This same comet will pass close to Earth again in 2032. These and other cometary close approaches to Earth are discussed in a future "Special Topics" presentation.

COMET OF THE WEEK: THE GREAT COMET OF 1843

Perihelion: 1843 February 27.91, q = 0.006 AU

Nighttime views of the Great Comet of 1843. Left: Painting by Charles Piazzi Smith, from eyewitness accounts. The date is unclear, but would have been around March 6, 1843. Right: A painting of the comet around March 23, 1843, attributed to D.A. Hardy. The constellation of Orion is above the comet's tail to the upper right of center.

For the first time in "Ice and Stone 2020," a Kreutz sungrazer is my "Comet of the Week." Some of the members of this group of comets have been among the brightest and most spectacular comets in all of recorded history, and as a group they are of immense scientific interest. The entire group of Kreutz sungrazers is the subject of a future "Special Topics" presentation, and several additional members will be future "Comets of the Week."

In addition to being called the "Great Comet of 1843," this object is sometimes called the "Great March Comet," and its formal designations are 1843 I (old style) and C/1843 D1 (new style). The earliest reported observation was apparently made on the evening of February 5, with an additional observation on the 11th; unfortunately, there are no details as to who and where (the "source" being a newspaper story at the time), although the comet must have been at least somewhat bright to have been casually noticed and would also have been low in the southwestern sky after dusk.

Observation reports in the days immediately thereafter are rather spotty, but the comet should have brightened rapidly while its elongation was shrinking steadily as it approached perihelion at the end of the month. On February 27 and 28, around the time of perihelion, the comet was widely observed from around the world in broad daylight as a brilliant object a few degrees from the sun; it was described as being as bright as Venus and possibly as bright as the crescent moon, and it exhibited a tail 2 to 3 degrees in length.

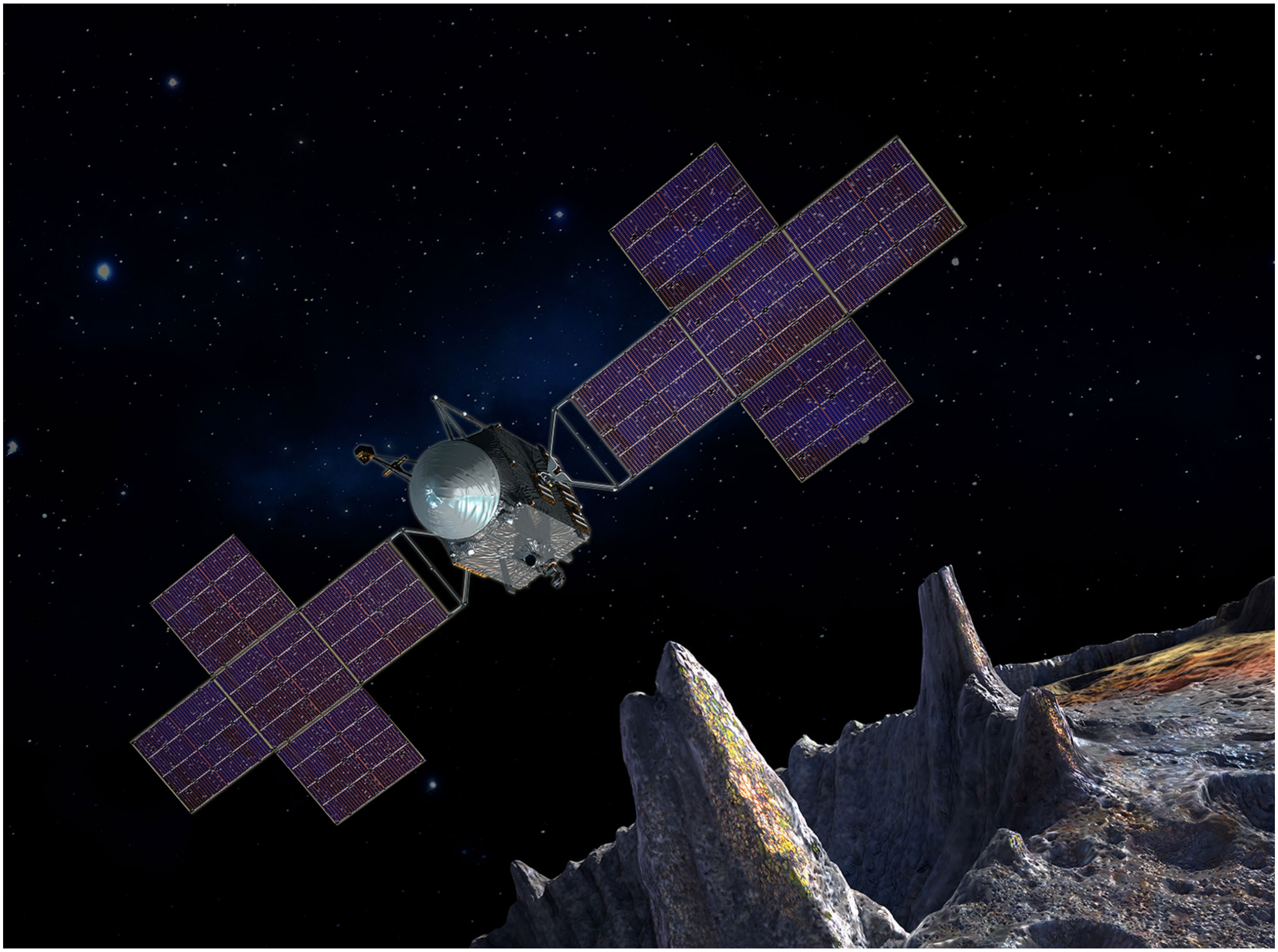
Normally the orbits of Kreutz sungrazers strongly favor viewing from the southern hemisphere, but this comet came at the right time of the year such that the northern hemisphere was able to obtain decent views as well, at least, after perihelion. Shortly after the beginning of March it began emerging into the evening sky during dusk, and its elongation rapidly increased as it passed closest to Earth (0.84 AU) on March 6, and afterwards. It was a bright object, perhaps around 1st magnitude, when it first appeared, and although it faded as it receded from perihelion, it maintained its brightness rather well, and remained a conspicuous naked-eye object throughout March. The main distinctive feature, meanwhile, of the Great Comet of 1843 was its long, straight, bright dust tail: this was measured as being 35 to 45 degrees long – with some measurements being as long as 65 degrees – throughout the entire month.

Although the comet was still a conspicuous object at the end of March, it apparently faded rapidly thereafter. It appears to have dropped below naked-eye visibility just after the first few days of April, and the final observation was reported on April 19.

The comet's long dust tail that was apparent in the nighttime sky was also long in physical terms – over 2 AU. This is the longest cometary tail that has ever been detected optically, although spacecraft observations of Comet Hyakutake C/1996 B2 indicate that its ion tail was even longer; this is next week's "Comet of the Week."

The Great Comet of 1843, near the sun in broad daylight, around the time of perihelion passage on February 27, 1843. The foreground scene is Table Bay near Cape Town, South Africa. The painting is by astronomer Charles Piazzi Smith.

SPECIAL TOPIC: RESOURCES IN "SMALL BODIES"

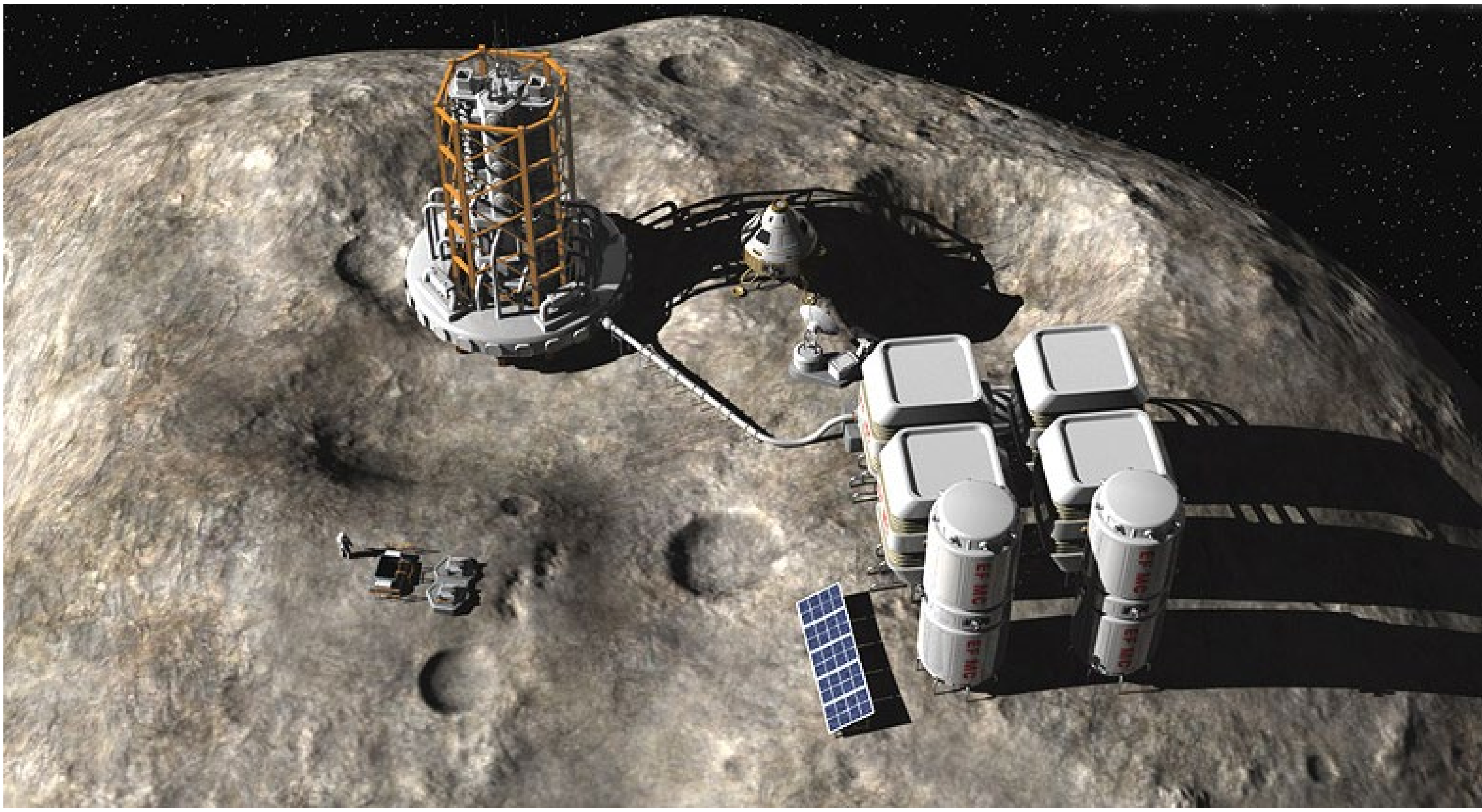


Artist's conception of NASA's Psyche mission arriving at asteroid (16) Psyche in 2026. Image courtesy NASA.

When it comes to their composition and internal structure, there is a wide variety among the asteroids. We know this primarily through two means: the study of the various meteorites that have landed on Earth – the subject of a future "Special Topics" presentation – and examination of their spectrum. Although asteroids do not give off their own light, they reflect light from the sun, and by examining the various features within these spectra we can deduce what materials might be present that are producing these features.

Although several taxonomic classifications for asteroids have now been defined, they essentially come in three broad types: a) those that are primarily made up of silicates, with some metals present – these are the most common; b) those that are primarily made up of metals (primarily iron and nickel, although numerous other metals (including gold- and platinum-group metals) are present as well); and c) the "carbonaceous" asteroids, primarily made up of organic compounds, and also containing a significant amount of water. The nuclei of comets can also be included among this last group.

The largest metallic asteroid was discovered 168 years ago this week – on March 17, 1852 – by the Italian astronomer Annibale de Gasparis from Naples. Now known as (16) Psyche, this asteroid orbits within the main asteroid belt with a period of 5.0 years, and appears to be approximately 225 km in diameter. As a result of a close flyby by a smaller asteroid in 1974, Psyche's mass, and consequently its overall average density, could be determined; this is approximately 4 gm/cubic cm, and together with spectroscopic studies this indicates a composition roughly 90% metallic iron with smaller amounts of nickel and other metals. It may be the remnant core of a protoplanet from the solar system's early days, and meanwhile it is



Artist's conceptions of potential mining operations on asteroids. Courtesy Christopher Barnatt/Explaining the Future.com.

the planned destination of NASA's upcoming Psyche mission, with launch scheduled for July 2022 and arrival planned for late January 2026. Psyche will be at opposition this coming December, and should be near 9th magnitude around that time.

The presence of so much metal in asteroids suggests that they could, in theory, be mined for use here on Earth. Our need of metals in our increasingly technological society correspondingly continues to increase, however the supplies of metals on Earth are finite, and moreover are increasingly difficult to identify and get to. (Most of Earth's metals are in its core, having settled there during Earth's formation billions of years ago.) Much of the metals on asteroids, meanwhile, are directly on their surfaces, and thus would be relatively easy to get to and to extract – provided we had the means to get there and to extract those metals in the first place.

Some years ago (now-retired) University of Arizona geologist John Lewis calculated that a metallic asteroid 2 km in diameter contains enough metals to be worth US$20 trillion in today's economy. On that same scale, the worth of the metal content in large metallic asteroids like Psyche would be numbered in the quadrillions of US dollars.

It isn't just here on Earth where the resources contained within asteroids can be useful, and the supply of "usable" asteroids isn't limited to just the metallic ones. Even the primarily-silicate asteroids – which, again, are the most common – contain a non-trivial amount of metals, as well as oxygen and other similar substances. If humanity is ever to develop a space-faring civilization, such materials can be utilized in a variety of ways, from construction of spacecraft to construction and maintenance of colonies on various bodies. The water within carbonaceous asteroids and within comets can be utilized in sustaining human colonies, but can also be dissociated into its constituent hydrogen and oxygen for usage as fuel for rockets and other machinery.

For any such future to take place, of course, this process must be economically feasible, and requires the development of a substantial infrastructure. In theory, there are several ways that the extraction of resources from asteroids and comets can proceed; probably the most obvious is on-site human operations, which however would also be the most expensive as it involves not only the development and transport of the on-site extraction machinery but also the life-support mechanisms for the human crews during transport and operations. The need for and expense of these life-support mechanisms is alleviated if the mining operations are autonomous, although this in turn would require the development of the appropriate artificial intelligence (AI) technology such that operations could proceed in a manner that requires little human interaction.

A somewhat alternative approach involves not traveling out far distances to asteroids to perform mining operations, but rather bringing them to Earth's vicinity where the mining can then be performed. For the near- and intermediate-term future, this limits us to near-Earth asteroids, however – as has been addressed in previous "Special Topics" presentations – there are still large numbers of these, quite a few of which are metallic and others of which are carbonaceous. The effort and expenses involved would also limit near-term efforts to very small asteroids, but even these still contain enough in the way of resources so as to make extraction efforts seemingly worthwhile.

Indeed, regardless of whatever approaches humanity might eventually deem as most appropriate, the earliest resource extraction efforts will almost certainly focus on near-Earth asteroids. In celestial mechanics, the most important quantity is "Delta_V," i.e., the changes in velocity necessary to make rendezvous and landing operations possible. The Earth already has a certain orbital velocity (roughly 30 km/sec)

Artist's conceptions of potential mining operations on asteroids. Courtesy Michael Oberschnedider.

and once a spacecraft has climbed out of Earth's gravity well – a process that itself requires a substantial Delta_V – it then possesses that same velocity. In order to rendezvous with, and potentially land upon, another body, the spacecraft needs to match velocities with that other body. This requires energy, which in turn requires fuel, and from an economic perspective, this in turn requires money.

To travel to, and potentially perform mining operations upon – and/or to bring back to Earth's vicinity – any asteroid, we need to find asteroids that require a minimum of Delta_V. What we would need, then, are asteroids that are traveling in near-circular orbits the same approximate size as Earth's orbit, and that have very small orbital inclinations with respect to Earth's orbit. As it turns out, a number of near-Earth asteroids have in fact been identified that have smaller Delta_V requirements than does travel to the moon. If we wish to travel to and retrieve such objects so as to bring them to Earth's vicinity, then we need these asteroids to be quite small; there are indeed a number of such objects, although here the primary difficulty involves detecting them in the first place. In 2013 Daniel Garcia Yarnoz and his colleagues at the University of Strathclyde in Glasgow, Scotland examined the various near-Earth asteroids that were known at that time and published a list of the top dozen "easily retrievable objects." These are all small objects – no more that a few meters in diameter – and the orbits of some of them are not especially well known, in fact only one has been observed since the publication of the list. Nevertheless, especially with the surveys that are presently operating, new candidate objects are being discovered fairly frequently.

This entire process was the aim of NASA's planned Asteroid Redirect Mission (ARM), proposed in 2013. Although the primarily purpose of ARM involved deflection strategies for potential incoming near-Earth asteroids – which itself is the topic of a future "Special Topics presentation – the procedures would also be applicable to potential resource extraction efforts. Had ARM proceeded as planned the mission – human-crewed – would have launched in late 2021, but it was cancelled in 2017.

In addition to the engineering and the economic issues involved, another facet that enters into the discussion of asteroid/comet resource extraction involves space law. Any such operations would, in theory anyway, be subject to international agreements and treaties, in a manner, for example, that activities on Earth's oceans are governed by the United Nations Convention of the Law of the Sea. In space, the primary governing document is the "Treaty on Principles Governing the Activities of States in The Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies" – generally referred to as the "Outer Space Treaty" – that became effective in 1967. The Outer Space Treaty prohibits signatory nations from claiming any celestial object, or portion thereof, as its own national territory, however – although the wording is not explicit – it has been interpreted to mean that private entities can extract materials from these bodies for various usages.

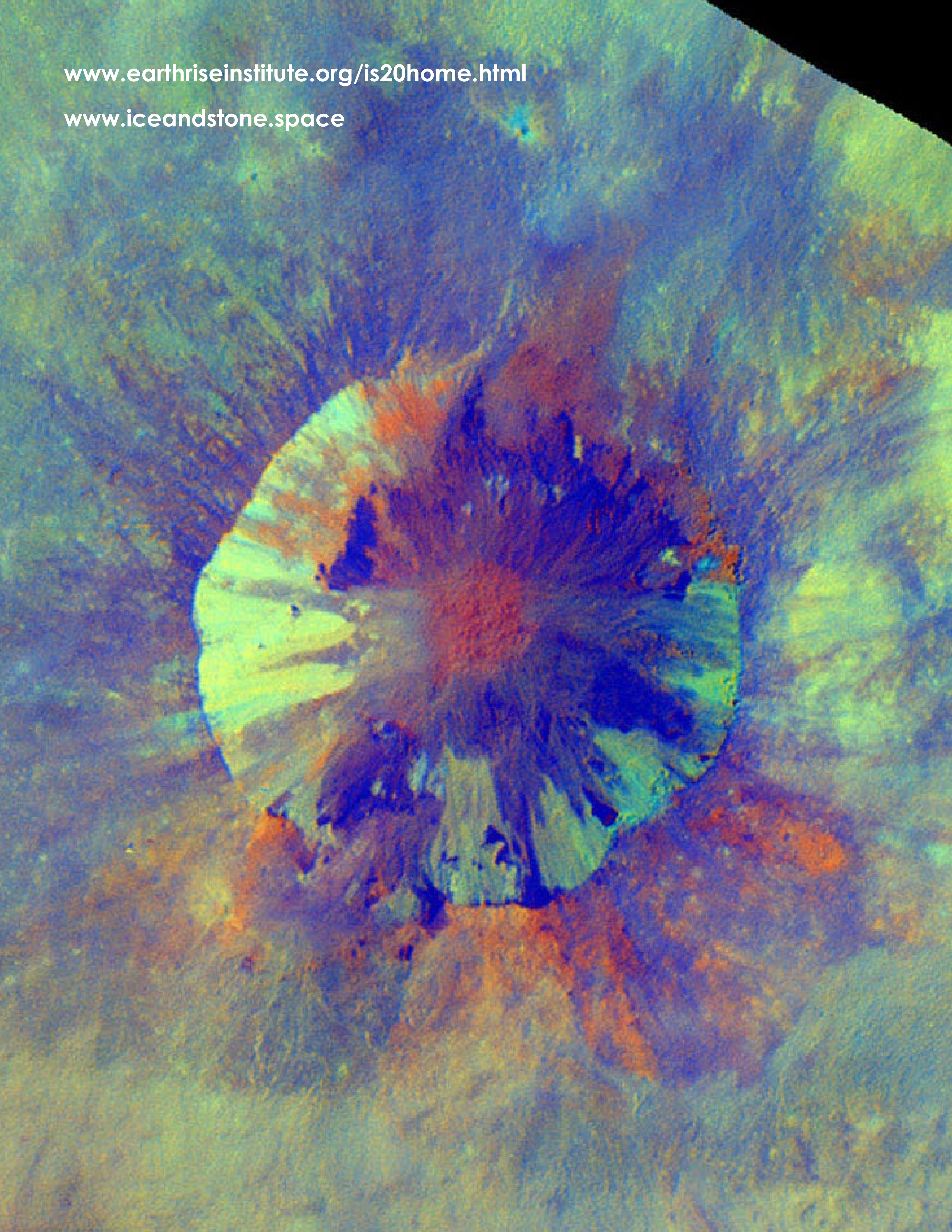
Some nations have gone further. In the U.S., Congress passed the U.S. Commercial Space Launch Competitiveness Act in 2015 which was then signed into law by then-President Barack Obama, and which among other things allowed and encouraged the commercial utilization of resources from asteroids. Luxembourg passed similar legislation two years later, and during forthcoming years, especially as the prospect of asteroid mining becomes more of a reality, we might expect that other nations would follow suit.

Deep Space Industries conception of an automated asteroid retrieval mission. Courtesy Deep Space Industries/Bradford Space, Inc.

A private company that wishes to explore the process of asteroid mining would seemingly face daunting challenges. The investments involved in developing the necessary infrastructure would be enormous, and many years, conceivably decades, might elapse before there could be any significant return on those investments. In such an environment, the most likely scenario would seem to be some sort of public-private partnerships involving governmental agencies like NASA and other national (or international, in the case of ESA) space agencies, although even here funding is subject to considerations of what the respective publics might be willing to invest. In the long run, however, if the effort can be maintained and the necessary infrastructure can be developed, the potential rewards are enormous; there are at present studies that have been performed and which indicate the net worth of potential operations on various known asteroids; even some of the near-Earth asteroids have a net worth of a few hundred billion to a few trillion US dollars, and some of the main-belt asteroids have a net worth of "hundreds of trillions" of US dollars.

The first preliminary efforts towards such a future have already begun. The firm Planetary Resources, co-founded in 2009 by space entrepreneurs Peter Diamandis (founder of the X-Prize) and Eric Anderson (CEO of the firm Space Adventures) with the goal of developing a resource extraction program, has launched a couple of small proof-of concept satellites (Arkyd 3 Reflight, deployed from the International Space Station in 2015, and Arkyd 6, launched in 2018. Initially Planetary Resources planned to devote its primary efforts towards finding near-Earth objects that contain significant amounts of water that can then be utilized as rocket fuel., however in late 2018 it was acquired by the firm ConsenSys and those efforts have since been de-emphasized. A similar company, Deep Space Industries, was founded in 2013 by, among others, long-time commercial space advocate Rick Tumlinson, and in fact I served on its Board of Advisors, however DSI was acquired by Bradford Space, Inc. at the beginning of 2019 and its originally planned efforts towards resource extraction from asteroids/comets are on hold for at least the time being.

To adopt a long-range view, if humanity is ever to expand into the solar system beyond Earth's vicinity, it will need to develop a "live-off-the-land" mindset and infrastructure that will certainly need to include the extraction of necessary resources from the bodies that are out there, most definitely including asteroids and comets. The challenges are enormous and the necessary investments – financial and otherwise – are large, but the eventual payoffs from these would involve nothing less than the survival and growth of humanity. I would like to think that some of the "Ice and Stone 2020" participants might one day be involved in endeavors such as these.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