ICE & STONE 2020

WEEK 53: DECEMBER 27-31

Presented by The Earthrise Institute

#53

Authored by Alan Hale

THIS WEEK IN HISTORY

DECEMBER **27** 28 29 30 31 1 2

DECEMBER 27, 1984: A team of American meteorite hunters finds the meteorite ALH 84001 in the Allan Hills region of Antarctica. This meteorite was found to have come from Mars, and in 1996 a team led by NASA scientist David McKay reported the presence of possible "microfossils" and other evidence of potential biological activity within it. This is the subject of a previous "Special Topics" presentation.

DECEMBER 27, 2020: The main-belt asteroid (41) Daphne (around which a small moon, named Peneius, was discovered in 2008) will occult the 7th-magnitude star HD 49385 in Monoceros. The predicted path of the occultation crosses Oregon, the northern Pacific Ocean, the southern part of the island of Sakhalin, far southeastern Russia, far northeastern China, northern Mongolia, and east-central Kazakhstan.

27 DECEMBER **28** 29 30 31 1 2

DECEMBER 28, 1969: Amateur astronomer John Bennett in South Africa discovers the comet now known as Comet Bennett 1969i. Around the time of its perihelion passage in March 1970 it became a bright naked-eye comet and it is the first "Great Comet" that I ever observed; it is a previous "Comet of the Week."

DECEMBER 28, 1973: Comet Kohoutek 1973f passes through perihelion at a heliocentric distance of 0.142 AU. Although it did not become the "Great Comet" that had been originally expected, it was nevertheless a moderately conspicuous naked-eye object and was an important comet scientifically. It is this week's "Comet of the Week."

DECEMBER 28, 2019: The ATLAS survey in Hawaii discovers the comet now known as Comet ATLAS C/2019 Y4. It was found to be traveling in the same basic orbit as the Great Comet of 1844 and is likely a trailing fragment of that object; unfortunately, it disintegrated as it approached perihelion this past May and did not become bright. It is a previous "Comet of the Week."

27 28 **DECEMBER 29** 30 31 1 2

DECEMBER 29, 2020: The Apollo-type asteroid (162173) Ryugu, destination of JAXA's Hayabusa2 mission (discussed in a recent "Special Topics" presentation, and having successfully delivered samples to Earth earlier this month), will pass 0.061 AU from Earth. It is currently traveling south-southeastward through the constellation Phoenix and will enter southern circumpolar skies in early January 2021; it is a rather faint object of 17th magnitude.

27 28 29 30 **DECEMBER 31** 1 2

DECEMBER 31, 2018: Having arrived at the near-Earth asteroid (101955) Bennu earlier that month, NASA's OSIRIS-REx mission goes into orbit around that object. OSIRIS-REx collected soil samples from Bennu this past October, and is expected to depart this coming March for a return to Earth in September 2023. The OSIRIS-REx mission is discussed in a previous "Special Topics" presentation.

DECEMBER 31, 2020: The main-belt asteroid (76312) 2000 ER138 will occult the 6th-magnitude star HD 45215 in Monoceros. The predicted path of the occultation crosses the Japanese island of Kyushu, the southern tip of South Korea, central northeastern China, southwestern Mongolia, northeastern Kazakhstan, eastern Russia, southern Finland, and central Sweden.

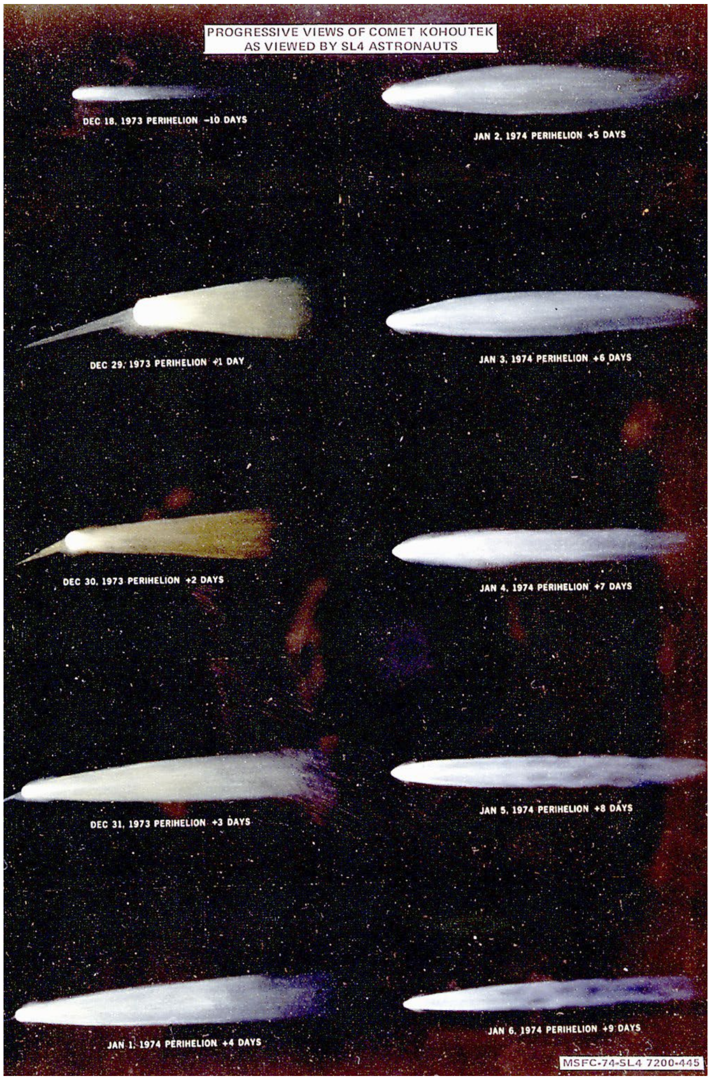
COVER IMAGE CREDIT:

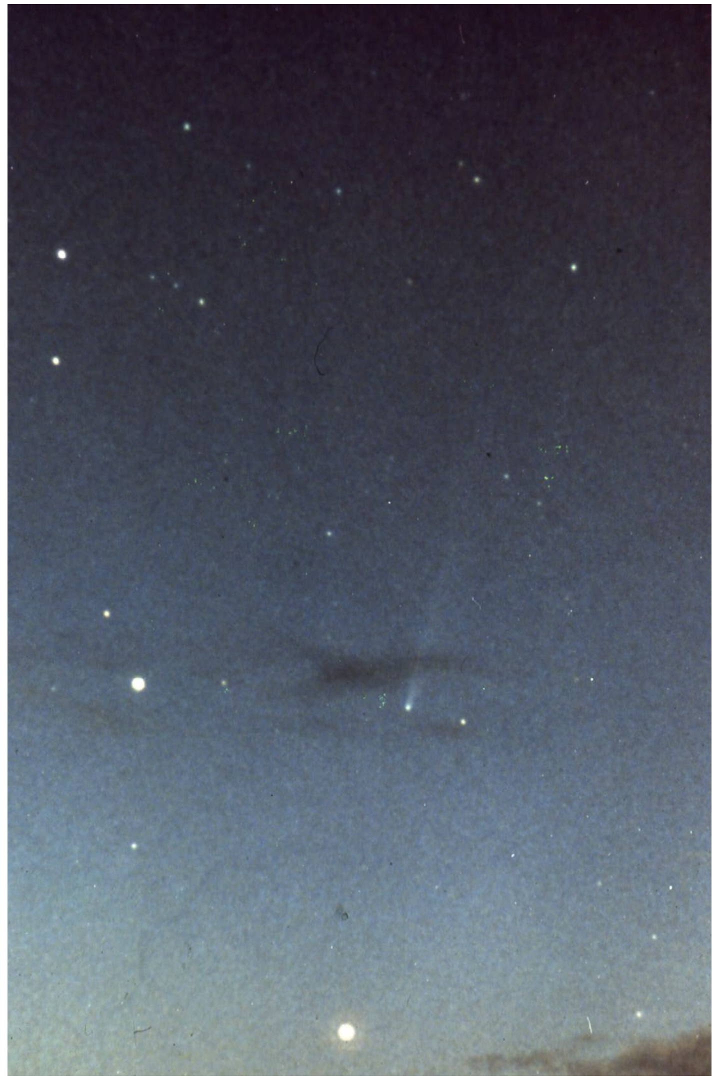
Front and back cover: Astronaut Ron Garan, Expedition 28 flight engineer, tweeted this image from the International Space Station on Aug. 14 with the following caption: "What a 'Shooting Star' looks like from space, taken yesterday during Perseid Meteor Shower." The image was photographed from the orbiting complex on Aug. 13 when it was over an area of China approximately 400 kilometers to the northwest of Beijing. The rare photo opportunity came as no surprise since the Perseid Meteor Shower occurs every year in August.

Courtesy NASA/Ron Garan

COMET OF THE WEEK: KOHOUTEK 1973F

Perihelion: 1973 December 28.43, q = 0.142 AU





Left: Sketches of Comet Kohoutek (made by astronaut Edward Gibson aboard Skylab during December 1973 and January 1974. Courtesy NASA. Right: Comet Kohoutek on the evening of January 7, 1974. Courtesy Dennis di Cicco.

This comet's story starts about two years before its actual discovery, when Brian Marsden (at the IAU's Central Bureau for Astronomical Telegrams) performed some orbital calculations of the long-lost periodic Comet 3D/Biela (a previous "Comet of the Week"). The comet had not been seen since the mid-19th Century and had long been thought as having disintegrated, however Marsden calculated that if there was any surviving fragment it might pass close to Earth in late 1971. Despite several searches, nothing was found, which reinforced the overall consensus that Comet Biela had indeed completely disintegrated.

One of the people who had conducted searches for Comet Biela in late 1971 was the Czech astronomer Lubos Kohoutek, at the Hamburg Observatory in Germany. While he found no trace of the comet, he did nevertheless discover several previously-unknown asteroids, some of which were in favorable locations for recovery in early 1973. While attempting to recover these, Kohoutek discovered two comets, the second of these being a 16th-magnitude object in western Hydra that first appeared on a photograph taken on March 7 – my 15th birthday, incidentally.

This particular comet was located at a heliocentric distance of 4.75 AU at the time of its discovery, but once orbital calculations revealed that it was over nine months away from perihelion passage which would take place at the very small heliocentric distance of 0.14 AU, excitement began to build rapidly within the astronomical community, as it appeared likely that a true "Great Comet," perhaps even the "Comet of the Century," was on the way in. Some of the initial forecasts, in fact, suggested a peak brightness as bright as magnitude -10, and even though these were later "downgraded" to about magnitude -3 or -4, this still nevertheless indicates a very bright comet, and the world waited . . .

Comet Kohoutek had brightened to about 14th magnitude by the time it disappeared into evening twilight in early May. When it emerged into the morning sky during the latter part of September it was close to 11th magnitude, somewhat fainter than expected, and while it brightened steadily after that, it did so more slowly than was expected. It became visible to the unaided eye during late November and was near 4th magnitude, with a tail a few degrees long, in early December, but was only about 3rd magnitude when it disappeared into the dawn a few days after mid-month.

An example of Comet Kohoutek in popular media. The cover of the 1974 album "Mysterious Traveler" from the jazz ensemble Weather Report. Courtesy Columbia Records.

Around the time of its perihelion passage Comet Kohoutek was too close to the sun to be visible from the ground, but it was detected rather easily from space. It appears to have undergone an outburst in brightness right around perihelion, as images taken by coronagraphs aboard NASA's Skylab space station and aboard the Orbiting Solar Observatory 7 (OSO-7) satellite suggest it may have been as bright as magnitude -3. Astronauts aboard Skylab and aboard the Soviet Union's Soyuz 13 mission observed it, and according to the Skylab astronauts it was as bright as magnitude -2 the day after perihelion, with a distinct anti-tail, although it faded somewhat rapidly and the anti-tail all but disappeared over the subsequent days, even though the main tail grew longer.

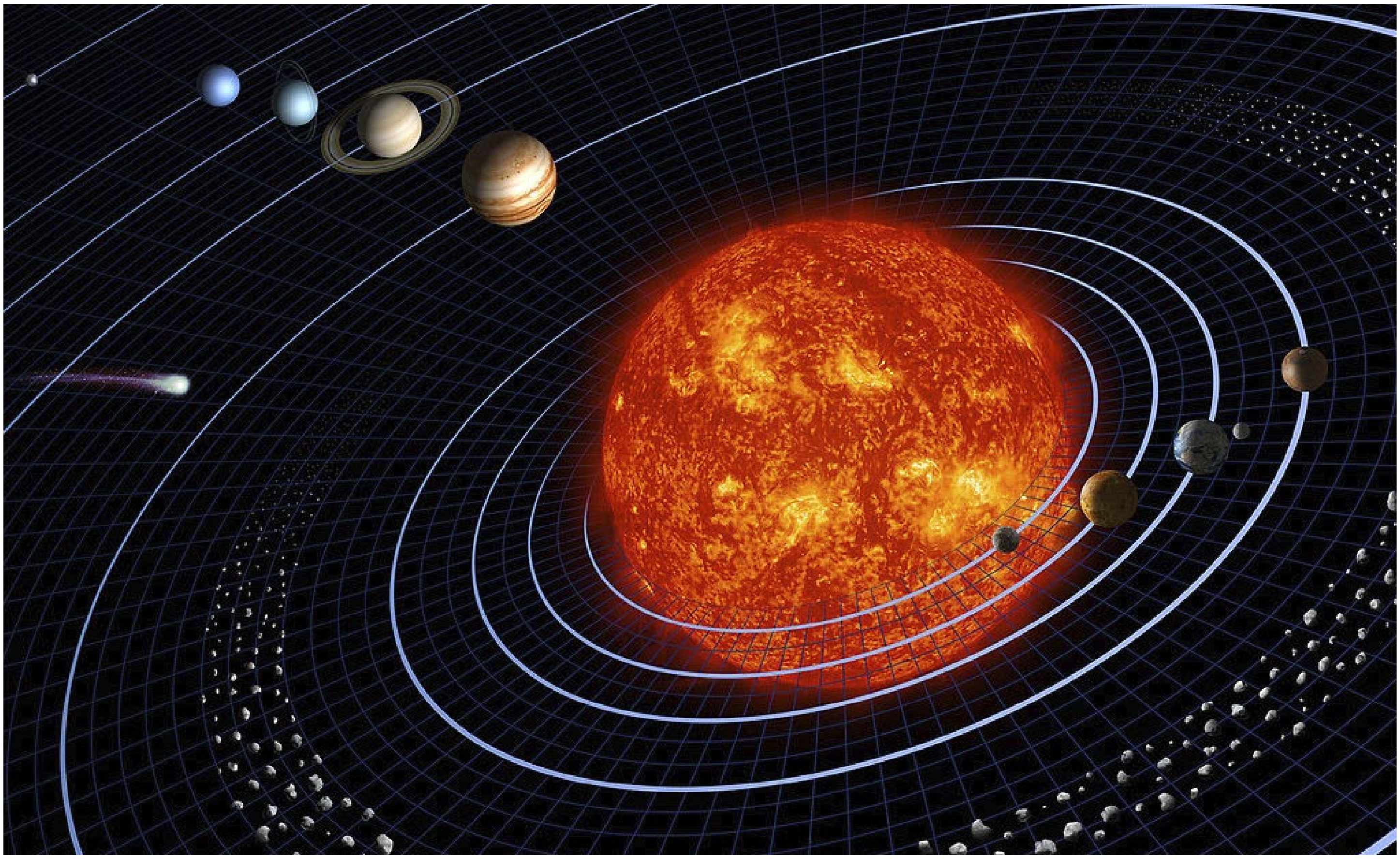
The comet was perhaps near magnitude 0 when it first became visible in the evening sky right at the very end of December, but had faded to 2nd magnitude by the time it became widely observed during the first week of January 1974. The tail reached a maximum length of about 15 degrees around mid-month – around the time of closest approach to Earth, 0.81 AU – but the comet itself dropped below naked-eye visibility by the end of January. It was followed telescopically until April, and after conjunction with the sun was photographed for one last time in early November, by which time its heliocentric distance had increased to 5 AU and it had faded to magnitude 22.

Although Comet Kohoutek did become a relatively decent naked-eye object when viewed from dark rural sites, it clearly was not the "Comet of the Century" that some of the initial forecasts suggested. A significant part of the reason for this is that Comet Kohoutek was a first-time visitor from the Oort Cloud, and as was discussed in the "Special Topics" presentation on "Great Comets," such objects tend to be unusually bright and active when at larger heliocentric distances but this activity level will often slow down dramatically as they approach perihelion. Indeed, compared to some other first-time Oort Cloud comets that have appeared since then, Comet Kohoutek's performance wasn't all that poor.

While it might not have been a "Great Comet," Comet Kohoutek was nevertheless a rewarding and productive comet from a scientific perspective. It was, for example, the first comet to be observed by an interplanetary spacecraft, as NASA's Mariner 10 mission obtained ultraviolet observations of it while en route to Venus. It was also the first comet to be extensively observed in the radio part of the electromagnetic spectrum, and among other substances organic molecules like methyl cyanide and hydrogen cyanide were detected inside of a comet for the first time.

The general public, certainly, which had been expecting the "Comet of the Century," was to a large extent greatly disappointed, and even today Comet Kohoutek is often associated with the cometary equivalent of a "fizzle." While part of this was due to the comet's slower rate of brightening due to its being a first-time visitor from the Oort Cloud, a non-trivial part of this is also due to widespread over-hyping in the popular media, and the ignoring of the more conservative predictions once astronomers started making those. The comet ended up being featured quite a bit in the popular media of the time, including within published stories, television programs, music, and even within comic strips, and at least one religious cult in the U.S. incorporated its appearance into their beliefs. Now that it has been "broken in," so to speak, perhaps it might put on a better show to anyone who is around to see it when it returns 75,000 to 80,000 years from now.

SPECIAL TOPIC: PUTTING IT ALL TOGETHER



The solar system (not to scale!) as I knew it in the mid-1960s. Courtesy NASA.

When I first began reading about the solar system as an elementary school student in the mid-1960s, it seemed to be a much simpler place than what we know today. There was the sun, around which orbited nine planets; some of these planets had moons, Jupiter having the most with 12. Between Mars and Jupiter was the asteroid belt, and occasionally some small asteroids might pass closer to the sun, and meanwhile there were also the occasional comets, some of these being of short-period while others were of longer period, that passed through the inner solar system. While some of the planets showed features that could be examined telescopically, for the most part they – and certainly their moons – were little more than dots of light in the sky, and that was definitely true for the asteroids as well. All told, everything was relatively quiet and orderly.

The solar system that I know today is much different than that. I can certainly attribute part of this to my own maturing and development as a person, to all the increased reading I have done since those early days, and to a career as a scientist where I have made some of my own contributions towards the study of the solar system. However, a large part is also due to our tremendously increased body of knowledge of the solar system, which has been fueled to a large extent by the development of telescopes and imaging technology which has made our observations much more extensive and proficient, and to computer technology which not only aids that endeavor but also allows us to develop mathematical models of the physical processes involved. Then there are all the spacecraft missions that have flown during those decades, many of which have visited all the planets as well as several of their moons, and have transformed those objects from point of light into unique and detailed individual worlds. Additional spacecraft missions have visited several of the asteroids and comets, and have enormously increased our knowledge and understanding of these objects as well.

One of the major steps in this process of our increased understanding has been the discovery of other planetary systems outside our own; the census of these now numbers several thousand, with more being discovered all the time. As was covered in last week's "Special Topics" presentation, we have also detected numerous stars that are accompanied by surrounding disks of material that are in the active process of forming planets. The combined study of all of these objects has told us that planetary systems are very commonplace in the Galaxy (and presumably the universe as a whole), and while each planetary system is unique in its characteristics, the underlying processes by which they form appear to be the same. Thus, by examining all these, we are able to glean significant understanding into our own origins.

Last week's "Special Topics" presentation discussed this basic underlying process, including the role played by the objects called "planetesimals" and the larger "protoplanets" (and how these objects came into existence in the first place). While many of these objects indeed went on to become incorporated into forming the planets we see today, those that didn't ended up having different fates. There were a lot of these objects in the solar system during that era, and some of them, due to gravitational influences of already-formed planets – especially Jupiter – were sent into the sun. Many others were ejected into the far outer solar system, and still others were ejected from the solar system altogether and into interstellar space. Yet others have remained within the inner solar system as "leftovers" from the planet formation process, and it is likely that Jupiter's gravitational influences prevented the formation of additional planets in these regions, especially in the part of the solar system we now call the "main asteroid belt."

A field of stars, in and around the constellation Centaurus. The globular star cluster Omega Centauri is at left, and the bright stars Beta (upper) and Alpha (lower) Centauri are at right. Exoplanet discoveries over the past couple of decades suggest that most, if not almost all, of the stars in this image – and everywhere else – are accompanied by planetary systems, formed by the same processes by which Earth and the other planets in our solar system formed.

These "leftovers" are the "small bodies" that we see today. The planetesimals that are made up primarily of "hard" materials like silicates and metals are what we now call "asteroids," while those that are made primarily of more "volatile" substances like ices and frozen gases are what we now call "comets." There are even a few leftover "protoplanets" around: the large main-belt asteroids (1) Ceres and (4) Vesta are likely such objects, and the large metallic asteroid (16) Psyche that has been discussed in a few previous "Ice and Stone 2020" presentations may well be the remnant metallic core of a protoplanet.

Comets cannot survive in the warm regions of the inner solar system for very long before their ices disperse into interplanetary space. The fact that we continue to see them, 4½ billion years after the solar system formed, means that there must be reservoirs of them in the colder regions of the outer solar system that continuously replenish the supply of them. The Kuiper Belt beyond Neptune and the Oort Cloud in the far outer solar system – both of which are subjects of respective "Special Topics" presentations – are these reservoirs, and via various gravitational influences that are discussed in those presentations there continue to be significant numbers of them that are brought into the inner solar system.

Since they are the "leftovers" from the planet formation process, asteroids and comets are believed to be relatively pristine and "unprocessed" objects from the early days of the solar system. There is thus much interest among scientists in studying these objects, both from the ground and, when feasible, by visiting spacecraft, since we can then gather insights into the conditions that existed when the planets – including, certainly, Earth – were forming. Some of the substances that have been detected within these objects match those that have been detected within interstellar gas and dust clouds, strengthening the idea that our solar system had its origins in such an environment. Comets, and quite a few asteroids as well, contain significant amounts of water, and thus it would appear that the early Earth received its water from these objects as it was forming. Many of these objects, including some of the meteorites that have fallen on Earth, contain various organic substances, including amino acids and other organic compounds associated with biological activity, and it accordingly would seem that Earth – and, presumably, other planets as well – received the basic raw materials of life from these objects early in their history.

There is, certainly, much that we still don't know about the overall processes by which Earth and the other planets formed, and as covered in some of the previous "Ice and Stone 2020" presentations, there have been observations from time to time that have introduced complications into our understanding of these processes. But the learning process continues,

Some scenes of Earth. The raw materials that eventually produced these scenes were originally brought to Earth by comets and asteroids early in its history. Photographs courtesy Vickie Moseley.

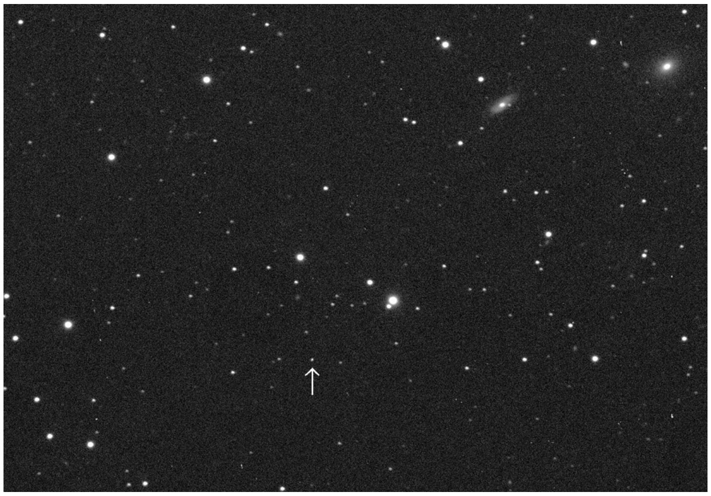
and there are still many objects to examine that, in time, should give us a firm handle into understanding our origins. (Indeed, an example of this occurred just a few months ago when a research team led by Laurette Piani at the Universite de Lorraine in France concluded that a large part of Earth's water may have arrived via a rare type of meteorite called an "enstatite chondrite.") I would like to think that perhaps some of the "Ice and Stone 2020" participants will be a part of this continuing endeavor.

It is clear from the craters we see on the moon and on Mars and on other planets that the planet-building process has continued from the solar system's early days. Indeed, the large number of asteroids in near-Earth space that have been detected during recent decades, together with events like the impacts of Comet Shoemaker-Levy 9 into Jupiter in 1994 and the meteorite explosion over Chelyabinsk, Russia in 2013, tells us that this process continues today. We've learned over the decades since I first started reading about the solar system that impacts by objects from space can have profound effects on our natural history, as was demonstrated by the impact 66 million years ago that brought an end to the era of dinosaurs and accordingly made our own existence possible.

An example of an enstatite chondrite meteorite. This is a segment of the Abee meteorite that fell in Alberta in 1952; this fragment is on display at the Royal Ontario Museum. Courtesy Captmondo, licensed via Creative Commons.

An impact event of this magnitude happening again would pretty much spell the end of human civilization on Earth as we know it. Although the chances that such an event will take place during the lifetimes of those of us alive on Earth today are extremely remote, over long enough timescales – tens to hundreds of millions of years – such an event is inevitable. There are also the impacts by smaller objects that, while not global in scale in terms of the damage they might cause, can nevertheless wreak damage over a local and regional scale, and these events occur much more frequently. As a result of the comprehensive survey programs that have become operational within the past couple of decades we have begun to be able to identify potentially threatening objects well in advance, and while there no immediate major threats – that we know about – at this time, we have also started thinking about counter-measures to take in case such a threat does materialize at some point in the not-too-distant future. This will continue to be an ongoing process for at least the near- to intermediate-term foreseeable future, and perhaps some "Ice and Stone 2020" participants might become involved in this effort.

At the same time, while some asteroids and comets might present a potential threat to our civilization here on Earth, they also present an opportunity. Many of these objects contain resources, such as water, silicate materials, and metals that we can utilize here on Earth and – if humanity decides it wants to proceed in such a direction – on colonies on other worlds of the solar system and in the vehicles that we would utilize to get there. There are numerous



Left: An image I took of main-belt asteroid (23238) Ocasio-Cortez with the Las Cumbres Observatory facility at McDonald Observatory in Texas on November 4, 2019. This asteroid was discovered by the LINEAR program in New Mexico on November 20, 2000, and was named for then-high school student Alexandria Ocasio-Cortez for her winning second place for her microbiology project at the 2007 Intel International Science and Engineering Fair, held in Albuquerque, New Mexico. Right: Photograph I took of Comet Hale-Bopp on the morning of March 21, 1997.

technological and engineering challenges involved in developing an appropriate infrastructure for the extraction of these resources, as well as various economic and legal issues that would need to be resolved, but none of these challenges are insurmountable, and if and when there comes a time when these challenges are overcome, the sky would literally be the limit. It gives me great pleasure to think that someday some of the participants in "Ice and Stone 2020" might be a part of such a grand endeavor.

Throughout human history the people of Earth have gazed in awe and wonder at the comets that have come by, and have incorporated them into our art, our literature, our music, and even our religions. As we have become aware of the asteroids over the past couple of centuries, we have done the same thing with these objects as well. There will always be a need in the human psyche for these emotional connections to the surrounding universe within which we live, and I hope that there are some "Ice and Stone 2020" participants who will help us in establishing and maintaining those connections.

I appreciate all the students, educators, and everyone else who have been with me during this journey over the course of this past year. It is my hope that all the "Ice and Stone 2020" participants have gained on understanding of the "small bodies" of the solar system, of the role these objects have played in our past, that they are playing in our present, and that they will continue to play in our future. The story of that future has not been written yet; may all of you be a part of writing a story of the future that is worthy of the best of humanity.

Earth, our home . . . and, for now at least, the only home we have. Courtesy NASA.

www.halebopp.org

www.iceandstone.space

PDF booklet prepared by RocketSTEM