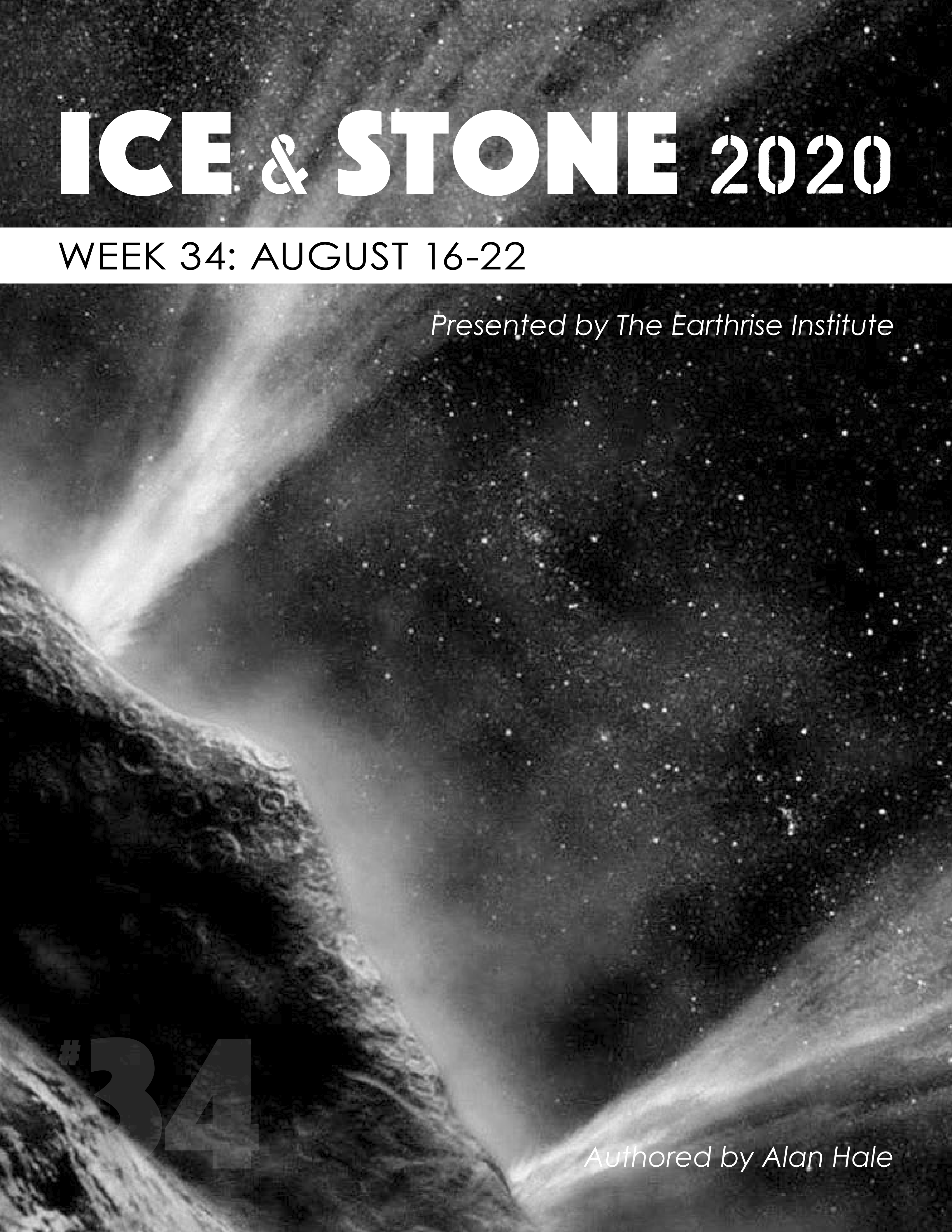
ICE & STONE 2020

WEEK 34: AUGUST 16-22

Presented by The Earthrise Institute



#34

Authored by Alan Hale

THIS WEEK IN HISTORY

AUGUST **16** | 17 | 18 | 19 | 20 | 21 | 22

AUGUST 16, 1898: DeLisle Stewart at Harvard College Observatory's Boyden Station in Arequipa, Peru, takes photographs on which Saturn's outer moon Phoebe is discovered, although the images of Phoebe were not noticed until the following March by William Pickering. Phoebe was the first planetary moon to be discovered via photography, and it and other small planetary moons are discussed in last week's "Special Topics" presentation.

AUGUST 16, 2009: A team of scientists led by Jamie Elsila of the Goddard Space Flight Center in Maryland announces that they have detected the presence of the amino acid glycine in coma samples of Comet 81P/Wild 2 that were returned to Earth by the Stardust mission 3½ years earlier. Glycine is utilized by life here on Earth, and the presence of it and other organic substances in the solar system's "small bodies" is discussed in this week's "Special Topics" presentation.

16 | AUGUST **17** | 18 | 19 | 20 | 21 | 22

AUGUST 17, 1877: Asaph Hall at the U.S. Naval Observatory in Washington, D.C. discovers Mars' larger, inner moon, Phobos. Mars' two moons, and the various small moons of the outer planets, are the subject of last week's "Special Topics" presentation.

AUGUST 17, 1989: In its monthly batch of Minor Planet Circulars (MPCs), the IAU's Minor Planet Center issues MPC 14938, which formally numbers asteroid (4151), later named "Alanhale." I have used this asteroid as an illustrative example throughout "Ice and Stone 2020" "Special Topics" presentations.

16 | 17 | AUGUST **18** | 19 | 20 | 21 | 22

AUGUST 18, 1877: The U.S. Naval Observatory in Washington, D.C., publicly announces the discoveries of Mars' moons Phobos and Deimos by U.S.N.O. astronomer Asaph Hall.

AUGUST 18, 1976: The then-Soviet Union's Luna 24 spacecraft successfully soft-lands in Mare Crisium on the lunar surface. After collecting 170 grams of soil samples it lifted off the following day and successfully returned these samples to Earth. Subsequent analysis of these samples produced the first evidence for the presence of water on the moon's surface. Lunar water is among the subjects covered in this week's "Special Topics" presentation.

AUGUST 18, 1985: Japan's Suisei mission is launched from the Uchinoura Space Center at the southern end of the island of Kyushu. Suisei would be among the international armada of spacecraft that would encounter Comet 1P/Halley the following March. The 1986 return of Comet Halley is a previous "Comet of the Week" and the results from the various spacecraft missions are discussed in that Presentation.

16 17 18 19 AUGUST 20 21 22

AUGUST 20, 2018: A team of scientists led by Shuai Li announces that NASA's Moon Mineralogy Mapper aboard India's Chandrayaan-1 mission has confirmed the presence of water ice at both the moon's North and South Poles. Lunar water is among the subjects covered in this week's "Special Topics" presentation.

AUGUST 20, 2022: NASA's Psyche mission is expected to be launched, with its destination being the large metallic main-belt asteroid (16) Psyche. Both the Psyche mission and its namesake destination are discussed in previous "Special Topics" presentations.

16 17 18 19 20 AUGUST 21 22

AUGUST 21, 1994: A team of astronomers led by Anita Cochran at the University of Texas utilizes the Hubble Space Telescope to obtain a series of very deep images in an attempt to detect very faint objects in the Kuiper Belt. Analysis of the images reveals the apparent presence of several dozen objects of about 28th magnitude, suggesting that the population of the Kuiper Belt may be on the order of 100 million objects. The Kuiper Belt is the subject of a future "Special Topics" presentation.

AUGUST 21, 2001: The Deep Ecliptic Survey at Cerro Tololo Inter-American Observatory in Chile discovers the asteroid 2001 QR322, the first-known "Neptune Trojan" asteroid. Trojan asteroids are the subject of a future "Special Topics" presentation.

16 17 18 19 20 21 AUGUST 22

AUGUST 22, 1888: A bright meteor is observed over Sulaymaniyah in present-day Iraq. According to reports at the time, meteorites fell "like rain" afterwards, killing one man and severely injuring another. The reports have only recently been unearthed and are still being examined; this happened too late to be included in the "Special Topics" presentation on meteorites, which included a discussion on deaths and injuries caused by meteorite falls.

AUGUST 22, 2016: A bright fireball appears over the desert regions of South Australia. Studies of its trajectory suggest that, prior to its entry into Earth's atmosphere, it may have been a temporary "moon" of Earth. Such objects are discussed in last week's "Special Topics" presentation.

COVER IMAGE CREDIT:

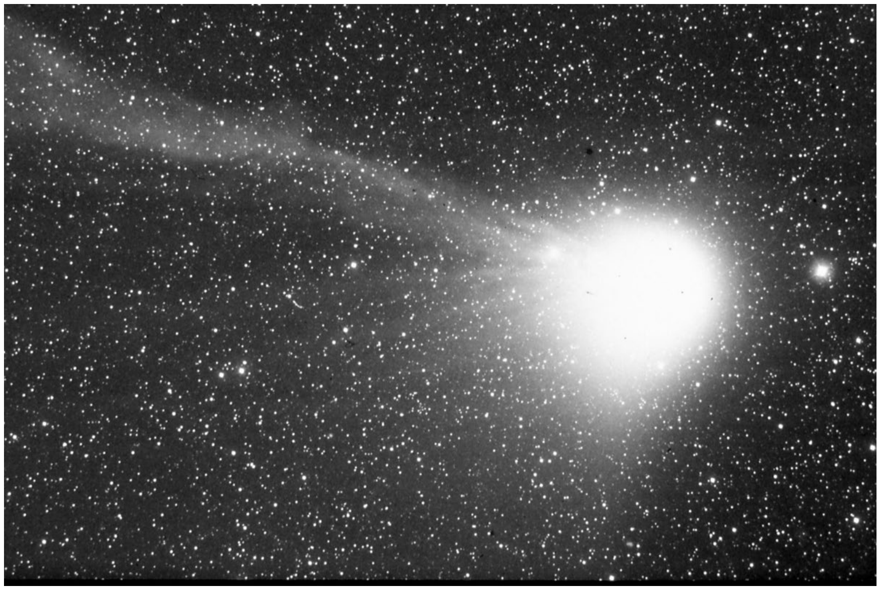
Front and back cover: An artist's concept depicting a view of comet Wild 2 as seen from NASA's Stardust spacecraft during its flyby of the comet on Jan. 2, 2004..

Courtesy NASA/JPL-Caltech

COMET OF THE WEEK: LEVY 1990C

Perihelion: 1990 October 24.68, q = 0.939 AU

I've commented in previous "Ice and Stone 2020" presentations that I spent several hundred hours unsuccessfully hunting for new comets before giving up that endeavor, and then accidentally discovered the comet that bears my name three years later. I did the bulk of my hunting during the late 1980s and early 1990s when I was a graduate student, during which time I had quite a few competitors who were also hunting comets, and it's a fair statement that some of these individuals were more successful at this endeavor than I was. One of these is David Levy – a longtime personal friend – who relocated from his native Canada to Tucson, Arizona in the late 1970s in large part to take advantage of that area's clear desert skies for comet-hunting. David would end up discovering eight comets between 1984 and 1994, and then successfully found a ninth one in 2006. In 1989 he joined the team of Eugene and Carolyn Shoemaker during their monthly searches for near-Earth asteroids at Palomar Observatory in California, and as a part of that collaboration he participated in the discovery of several additional comets, including Comet Shoemaker-Levy 9 1993e – a previous "Comet of the Week" – that impacted Jupiter in mid-1994.



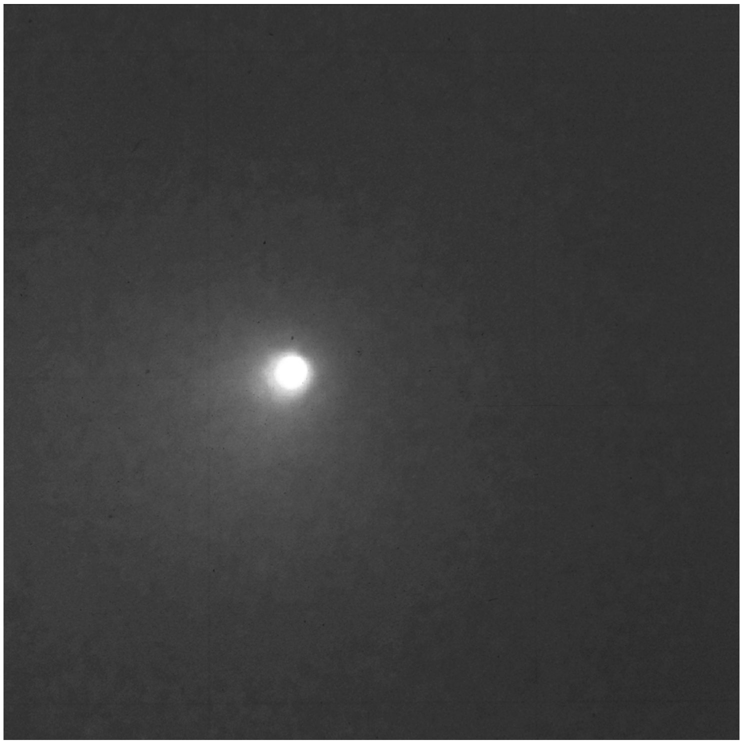
Comet Levy as photographed by its discoverer with the 46-cm Schmidt telescope at Palomar Observatory in California on August 22, 1990. Courtesy David Levy.

David discovered his sixth comet on the morning of May 20, 1990. Since he was heading out of town for an obligation that he could not miss he called me later that morning to ask me to confirm his discovery, which I successfully did the following morning. At that time it was a relatively condensed object of 10th magnitude located close to the northeastern "corner" of the "Great Square" of Pegasus. Comet Levy was approaching the sun and Earth, and it brightened rapidly over the next few weeks. By late June it was easily detectable with binoculars near 8th magnitude, and by the end of July it had reached 6th magnitude and could be detected with the unaided eye. It went through opposition just after mid-August and was closest to Earth (0.43 AU) a little over a week later, and around that time it reached a peak brightness near magnitude 3.5. Since the tail was more-or-less directed away from Earth it was not especially prominent, although I did measure a length of about three degrees late that month. As the comet pulled away from Earth during September the view of the tail became more "broadside" and I measured a length of about four degrees; meanwhile, it was also fading, and the brightness had dropped below 5th magnitude by the time the comet disappeared into evening twilight shortly

Photograph I took of Comet Levy on August 25, 1990.

before the end of that month.

After being in conjunction with the sun around the time of perihelion passage in late October – during which it remained accessible from the southern hemisphere – Comet Levy emerged back into the morning sky as a 7th-magnitude object in early December. It had a second, more distant opposition (1.15 AU) in mid-February 1991, and it remained near magnitude 7.5 around that time while exhibiting both a distinct main tail as well as a prominent and slightly shorter anti-tail. Afterwards it faded rapidly, fading beyond the range of visual detectability around the time of the one-year anniversary of its discovery. Larger telescopes continued to follow it until April 1992.



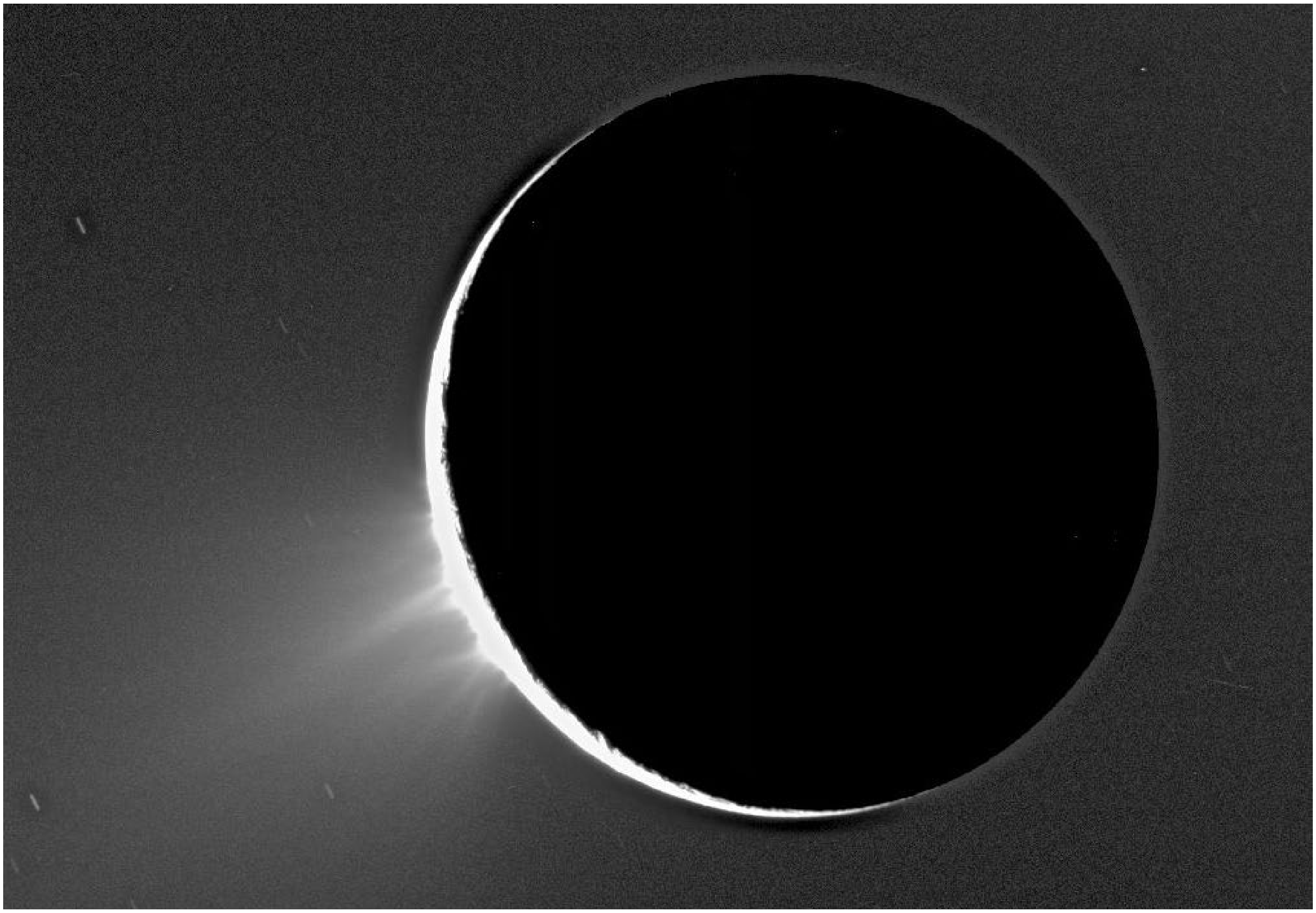
The inner coma of Comet Levy, as imaged by the Hubble Space Telescope on September 27, 1990. Courtesy NASA.

Among the scientific instruments used to study Comet Levy was the Hopkins Ultraviolet Telescope aboard the Space Shuttle-borne Astro-1 observatory, which had originally been planned for deployment in March 1986 to study Comet 1P/Halley but which had been delayed following the destruction of the Space Shuttle Challenger that January. From aboard Columbia on December 12, 1990, Astro-1 successfully observed Comet Levy for twenty minutes and, among other things, detected a large halo of carbon monoxide (possibly released from carbon/hydrogen/oxygen/nitrogen (CHON) particles like those detected around Comet Halley by ESA's Giotto mission) surrounding the coma. With the exception of the on-site observations of Comet Halley conducted by Giotto, this was the first detection of such a feature associated with a comet.

Comet Levy has the distinction of being the first comet to be observed by the Hubble Space Telescope. Hubble had been deployed from the Space Shuttle Discovery on April 25, 1990, but it was soon apparent that a defect in its optical system prevented images from being able to be brought to a proper focus – a problem that was fixed by a dramatic Hubble Servicing Mission performed by astronauts aboard the Space Shuttle Endeavour in late 1993 that installed would could be called "corrective lenses" on Hubble and restored its vision. In the meantime, the development of sophisticated image processing techniques was still able to help in producing images of remarkable clarity and detail. Hubble observed Comet Levy on September 27, 1990, and was able to resolve individual arc-shaped jets (emanating from the nucleus) within the very innermost coma. Since that time, and especially after the 1993 maintenance mission, Hubble has gone on to observe numerous additional comets as well as many, many other objects which have helped in completely revolutionizing our knowledge of the universe within which we live.

A pre-discovery trailed image of Comet Levy, from the blue print of the Second Generation Palomar Sky Survey, taken September 24, 1989. Courtesy Digitized Palomar Sky Survey.

SPECIAL TOPIC: THE "BUILDING BLOCKS" OF LIFE

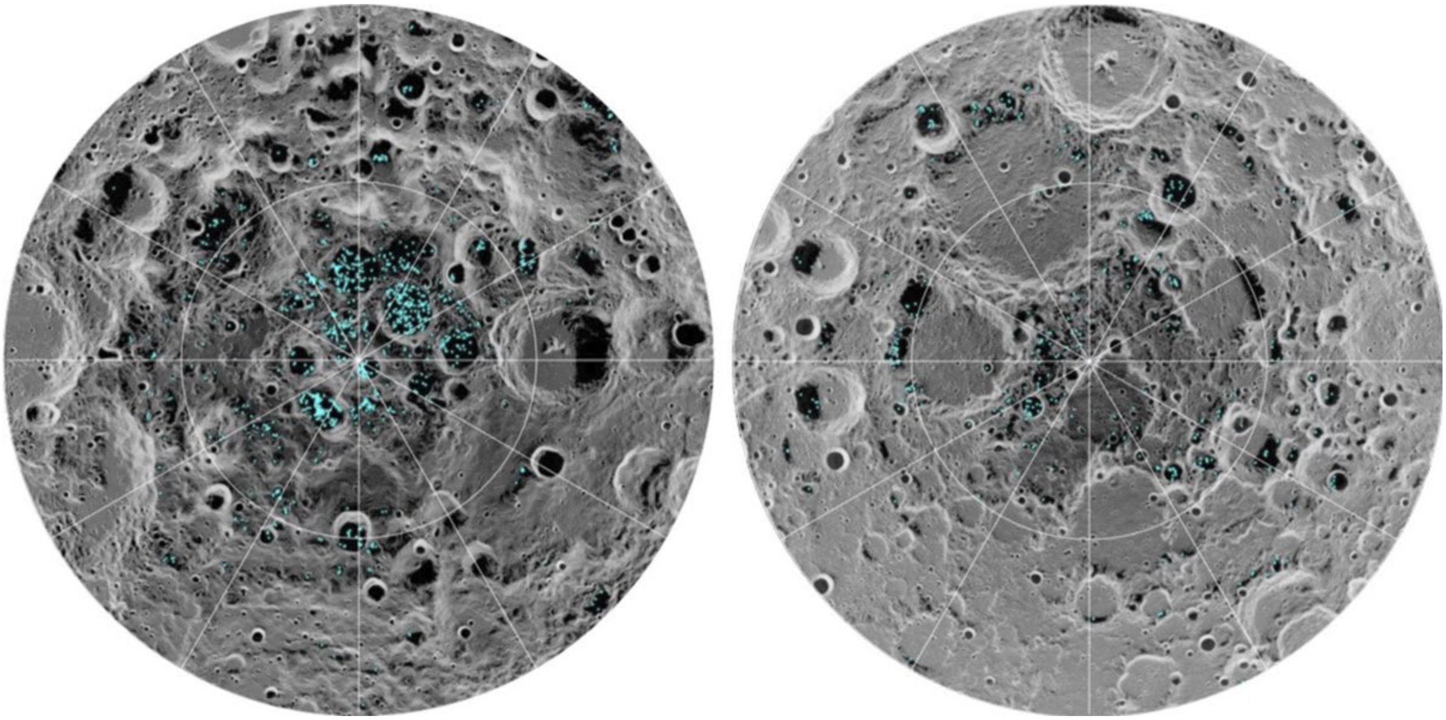


Water geysers erupting off Saturn's moon Enceladus, as imaged by the Cassini mission. Courtesy NASA.

The "Special Topics" presentation two weeks ago discussed the possibility that signs of life might exist within certain meteorites that have been found to have come from Mars, although it did so partially within the overall context of "are we alone?" Another part of that discussion revolves around how life on Earth – and, hopefully, elsewhere – got started in the first place, and in keeping with the overall focus of "Ice and Stone 2020" includes the roles that the "small bodies" of the solar system played in that process.

An important caveat here is that, when we discuss "life," we are essentially restricted to "life as we know it," i.e., the life that we find here on Earth. It is certainly conceivable that life with a completely different structure and nature can and has formed elsewhere, but in the absence of any information about that we have little choice but to go with what we know. The life we do know needs three things to exist and, presumably, to form: energy, water, and organic (i.e., carbon-containing) compounds. Most of the energy would presumably come from sunlight, and in particular – especially in stimulating the formation of life – higher-energy forms of sunlight like ultraviolet (which would have arrived at Earth's surface in relatively high quantities before the formation of the ozone layer), although geothermal activity, tidal forces, and decay of radioactive substances can also play a part.

Water, not too surprisingly, is one of the most abundant molecules in the universe, and it has been detected in many environments all over the place, including within large molecular clouds from which stars and planets are forming (including within planet-forming disks around young stars), and even within the atmospheres of exoplanets. It has been found all over the solar system, including, obviously, on Earth's surface and in its atmosphere; there is clear evidence that large amounts of water once flowed on the surface of Mars and there may still be quite a bit of subsurface water in the form of ice. Water ice has been found in the



The moon's South Pole (left) and North Pole (right) as imaged by NASA's Moon Mineralogy Mapper aboard India's Chandrayaan-1 mission. The blue dots indicate deposits of water ice in permanently shadowed craters. Courtesy NASA.

atmospheres of the giant planets, in particular Uranus and Neptune, and many of the moons of these worlds are also made up significantly of water ice. Water geysers have been found erupting off the surface of Saturn's moon Enceladus, and large worldwide oceans of subsurface liquid water are believe to lie under the surface of Jupiter's moon Europa and perhaps several other such bodies, including Pluto and – based upon just-published analyses of data from the Dawn mission – the largest main-belt asteroid, Ceres.

As was covered in the "Special Topics" presentation on Fred Whipple's comet model, a significant percentage of a comet's nucleus is made up of water ice, and indeed water has been detected in comets for the past three decades. As comets have impacted the various planets over the history of the solar system they would have delivered water to those bodies. Indeed, this appears to be the most likely explanation for the presence of water ice in what at face value appears to be among the harshest environments for it: the surfaces of Mercury and the moon. Radar observations of Mercury in 1991 suggested the presence of water ice in craters near Mercury's North Pole in 1991, a result which was confirmed by NASA's MESSENGER mission in 2012. The presence of water on the moon was first suspected in soil samples returned by the then-Soviet Union's Luna 24 mission in 1976 and the presence of ice in the moon's polar regions was strongly suspected in radar experiments conducted by the joint NASA/U.S. Defense Department Clementine mission in 1994. These conclusions were strongly reinforced by NASA's Lunar Prospector mission in 1998 and the Lunar CRater Observation and Sensing Satellite (LCROSS) mission which deliberately impacted a crater near the moon's South Pole on October 9, 2009, and completely confirmed by data taken by NASA's Moon Mineralogy Mapper aboard India's Chandrayaan-1 mission later that same year and announced in 2018. What appears to be happening on both worlds is that the water in impacting comets is ejected from the impact sites and transported – in the relatively weak surface gravity – to permanently shadowed craters in the polar regions. The temperatures in these environments are very cold, and over the lifetime of the solar system enough such impacts occur so that a non-trivial amount of water can accumulate.

For quite some time it was generally assumed that Earth had received its water primarily as a result of impacts by comets throughout its history. However, an analysis of the water content in several comets, including 1P/Halley, Hyakutake C/1996 B2, and Hale-Bopp C/1995 O1 – all previous "Comets of the Week" – has revealed that the ratio of deuterium to hydrogen atoms within their water is close to twice what it is in Earth's seawater. Indeed, results obtained by ESA's Rosetta mission indicate that the deuterium-to-hydrogen ratio in the water of Comet 67P/Churyumov-Gerasimenko is three times that of Earth's seawater. Meanwhile, an examination of Comet 103P/Hartley 2 – which was encountered by NASA's EPOXI mission in late 2010 at the same time that the comet was passing close to Earth – by ESA's infrared-sensitive Herschel Space Observatory indicates that the deuterium-to-hydrogen ratio in that comet is about

The surface of Saturn's moon Titan, imaged by ESA's Huygens lander on January 14, 2005. Tholins are believed to be responsible for the orangish coloration of the surface and atmosphere. Courtesy ESA/NASA/JPL/University of Arizona.

the same as that in Earth's seawater. At the very least, then, the overall picture is quite a bit more complex than what had been commonly believed, and it would seem that there were sources for Earth's water other than comets.

It is conceivable that the so-called "main belt comets," which are discussed in the forthcoming "Special Topics" presentation on "active asteroids," could have supplied, at least in part, the early Earth with its water. On the other hand, there are numerous asteroids that also contain significant amounts of water. The carbonaceous chondrite meteorites – which are the subject of their own future "Special

A water scene on Earth: from Cape Jervis, South Australia, looking towards Kangaroo Island. Photo by Vickie Moseley.

Topics" presentation – contain non-trivial amounts of water within their mineral structures, and it would then follow that the parent asteroids of these objects do as well. The large main-belt asteroid (24) Themis – roughly 200 km in diameter – is similar in composition to carbonaceous chondrites, and infrared observations obtained in 2009 indicate that its surface is almost completely covered with water ice. Infrared-sensitive observations have also detected emissions of water vapor from the largest main-belt asteroid, (1) Ceres, and just last year NASA's OSIRIS-REx mission detected the presence of hydrated (i.e., water-containing) clays on the surface of the near-Earth asteroid (101955) Bennu, and also detected eruptions of surface material – possibly caused by sublimation of water – on several occasions. (This mission is discussed in more detail in a future "Special Topics" presentation.) Whether or not this "asteroidal" water helps clear up the picture as to where Earth's water originally came from remains to be seen.

Simple organic molecules have been detected within comets for quite some time. More complex organic molecules, including formaldehyde and various long-chained polymers, were detected in and around Comet 1P/Halley by ESA's Giotto mission when it passed by that object in March 1986. Complex organic molecules like these have since been detected in more recent comets, including Comet Hale-Bopp in 1997, and recently by Rosetta during the course of its examination of Comet 67P/Churyumov-Gerasimenko; overall, Rosetta detected 16 different complex organic compounds, four of which (including acetone) for the very first time within a comet. Organic compounds have also been found in various asteroids, including (24) Themis and (1) Ceres, and also in various meteorites, especially in the carbonaceous chondrites. The presence of organic molecules known as "polycyclic aromatic hydrocarbons," or PAHs, in the Martian meteorite ALH 84001 was one of the lines of evidence cited as suggesting the presence of fossilized microbial life in that object, as was discussed in the "Special Topics" presentation two weeks ago.

A certain type of organic molecule known as a "tholin" is formed when high-energy radiation, for example, a cosmic ray, interacts with volatile materials such as ices. They do not form naturally on present-day Earth, but have been found in several places in the more distant solar system, such as on the surfaces of icy worlds like Pluto and some of moons of the outer planets; among other places, tholins are also found in both the atmosphere and on the surface of Saturn's moon Titan. They are not common further in, although at least one crater (Ernutet) on (1) Ceres contains them, and they have also been detected on (24) Themis and (by Rosetta) on 67P/Churyumov-Gerasimenko. In the far outer solar system, i.e., the Oort Cloud and the Kuiper Belt, tholins should be rather common, and indeed they have been detected on various Kuiper Belt objects and centaurs. The interstellar object 1I/'Oumuamua – the subject of a future "Special Topics" presentation – also appears to contain tholins, as does the recent interstellar Comet 2I/Borisov – a future "Comet of the Week." Tholins are distinctly reddish in coloration and thus their presence can often be inferred photometrically with different-color filters; among other things, they are believed to be at least partially responsible for the orangish coloration of Titan's atmosphere and surface that was detected by ESA's Huygens lander.

A fragment of the Murchison meteorite, displayed at the National Museum of Natural History in Washington, D.C. Copyright Basilicofresco, licensed via Creative Commons.

Certainly among the more intriguing of the various organic substances that have been detected in astronomical bodies are amino acids, which are utilized by life forms in the performance of basic biological activities. Amino acids have been detected within various carbonaceous chondrites, with over 15 different types of them being found within the Murchison meteorite, one of the most famous and studied of these objects. (Murchison will be discussed more thoroughly in the future "Special Topics" presentation on carbonaceous chondrites.) One of the simpler amino acids, glycine, has been detected in the material samples from Comet 81P/Wild 2 – the Week 1 "Comet of the Week" – that were returned to Earth by NASA's Stardust mission, and Rosetta also detected glycine in Comet 67P/Churyumov-Gerasimenko.

Finally, two nucleotide bases, uracil and xanthine, have been detected in the Murchison meteorite. Uracil is one of the four bases that make up molecules of ribonucleic acid (RNA).

I should stress that the presence of amino acids and organic compounds like uracil in meteorites like Murchison or in astronomical objects like comets does not mean that life itself is present in these objects. However, their presence, along with the large amounts of water that are present in the solar system, does suggest that the raw materials for life have been around since the early days of the solar system and that the mechanisms for delivering these materials to Earth have long been in action. The same would presumably be true for other potentially life-bearing worlds like Mars, Europa, and Titan, although whether or not life got started on those worlds, and survived like it has on Earth, remains unknown at this time. But in any event, in a very real sense the study of the "small bodies" of our solar system is an examination of our own origins.

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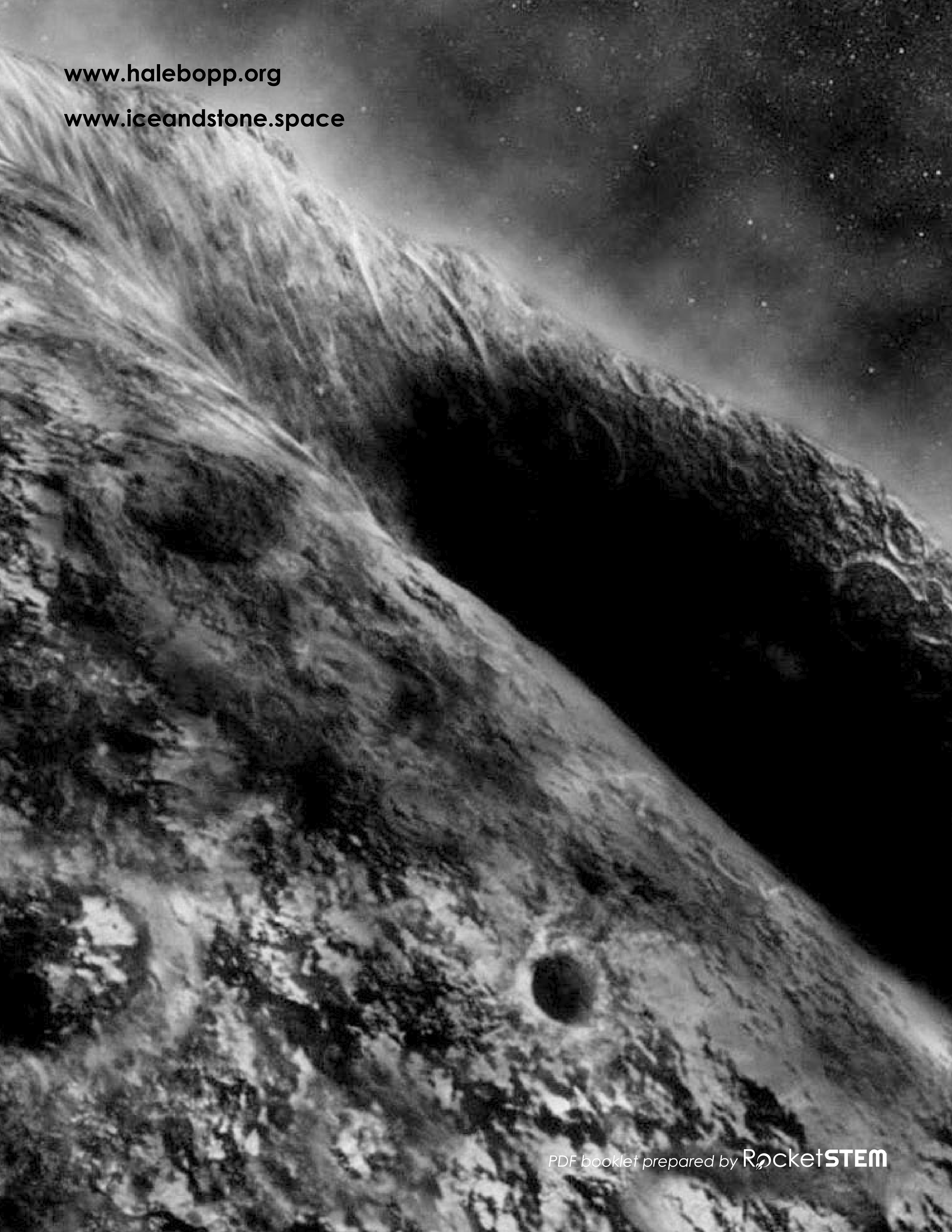

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