ICE & STONE 2020

WEEK 10: MARCH 1-7, 2020

Presented by The Earthrise Institute

#10

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 1	2	3	4	5	6	7

MARCH 1, 1705: British astronomer Edmond Halley publishes his calculations of the orbits of the comets of 1531, 1607, and 1682, concluding that they are individual returns of the same comet, and that that comet would return in 1758. His prediction turned out to be correct, and the comet has been named in his honor. The story of Halley's Comet is the focus of next week's "Special Topics" presentation, and the most recent return of the comet is next week's "Comet of the Week."

MARCH 1, 1744: The brilliant Comet de Cheseaux (new style designation C/1743 X1) passes through perihelion at a heliocentric distance of 0.222 AU. Later in the week its multiple tails rising above the horizon formed a dramatic sight in the dawn sky. An image of this comet appears in last week's "Special Topics" presentation.

MARCH 1, 1950: Fred Whipple publishes his paper, "A Comet Model: The Acceleration of Comet Encke" in the Astrophysical Journal. In this paper Whipple presents his "icy conglomerate" model of a comet's nucleus – now more commonly known as the "dirty snowball" model – which has now been verified by numerous observations including several spacecraft visits of comets. Whipple's model, and its verification, is the subject of this week's "Special Topics" presentation.

MARCH 1, 1984: JPL astronomer Hartmut Aumann and his colleagues publish their paper "Discovery of a Shell Around Alpha Lyrae" in the Astrophysical Journal. Aumann and his colleagues detected excess infrared radiation around the star Vega in data taken with the InfraRed Astronomical Satellite (IRAS) mission, one of the first clear signs of a protoplanetary disk, and first announced their discovery in October 1983. These disks are discussed in both previous and in future "Special Topics" presentations.

MARCH 1, 2020: The 6th-magnitude star HD 153890 in Scorpius (also known as V923 Scorpii) will be occulted by the main-belt asteroid (466) Tisiphone. Most of the predicted path of the occultation lies over open waters of the southeastern Indian Ocean, but the southwestern tip of Western Australia (just south of Perth) is in the path.

1	MARCH 2	3	4	5	6	7

MARCH 2, 2004: The European Space Agency's Rosetta mission is launched from Kourou, French Guiana. After flybys of the main-belt asteroids (2867) Steins in September 2008 and (21) Lutetia in July 2010, Rosetta arrived at Comet 67P/Churyumov-Gerasimenko in August 2014 and went into orbit around it, deployed the Philae lander, and then soft-landed on the comet's surface at the end of its mission in September 2016. The Rosetta mission is discussed as part of a future "Special Topics" presentation, and Comet 67P is a future "Comet of the Week."

MARCH 2, 2033: NASA's Lucy mission is scheduled for arrival at the Jupiter Trojan asteroid (617) Patroclus and its moon Monoetius. The Lucy mission and Trojan asteroids are covered in future "Special Topics" presentations..

MARCH 1 2 **3** 4 5 6 7

MARCH 3, 2021: NASA's OSIRIS-REx mission is scheduled to depart the near-Earth asteroid (101955) Bennu, which it has been orbiting since late 2018, and begin its return to Earth with collected soil samples. The OSIRIS-REx mission is discussed as part of a future "Special Topics" presentation..

MARCH 1 2 3 4 5 **6** 7

MARCH 6, 1961: Polish astronomer Kazimierz Kordylewski makes his first reported detection of the "Kordylewski clouds" located at the Earth-moon L4 and L5 Lagrangian points. Their existence would remain controversial for several decades but they appear to have been confirmed by a team of Hungarian researchers in 2018. They are discussed in a future "Special Topics" presentation.

MARCH 6, 1986: The Soviet Union's Vega 1 spacecraft passes approximately 10,000 km from the nucleus of Comet 1P/Halley and returns some of the first direct images of a comet's nucleus. The 1986 return of this comet is next week's "Comet of the Week" and the discussion there will include results from the various spacecraft missions.

MARCH 6, 2003: The LONEOS program in Arizona discovers the near-Earth asteroid now known as (196256) 2003 EH1. This asteroid has an orbital period of 5.5 years and travels in an orbit very similar to that of the Quandrantid meteor shower that peaks in early January, and may be the Quadrantids' parent object (and thus may be an extinct comet nucleus). It does not come within 1 AU of Earth again until 2041 and doesn't make any close approaches until one of 0.33 AU in December 2052.

MARCH 6, 2009: NASA's Kepler Space Telescope is launched from Cape Canaveral, Florida. For the next four years Kepler continuously surveyed a field of stars in the constellations Cygnus and Lyra looking for small brightness variations indicative of orbiting planets, detecting to date well over 2000 confirmed exoplanets with a similar number still awaiting confirmation. Kepler also detected significant brightness variations in the star KIC 8462852 (informally known as "Boyajian's Star") which are discussed in a previous "Special Topics" presentation.

MARCH 6, 2015: NASA's Dawn spacecraft arrives at the largest main-belt asteroid, and "dwarf planet," (1) Ceres and goes into orbit around it. Dawn spent the next 3 ½ years orbiting Ceres from a variety of distances and performed numerous scientific investigations, until the mission was terminated in late 2018 due to a lack of remaining fuel; Dawn remains in orbit around Ceres today. Ceres is discussed in Week 1's "Special Topics" presentation, and the Dawn mission is among those discussed in a future "Special Topics" presentation.

MARCH 7, 1973: Czech astronomer Lubos Kohoutek discovers a comet, designated Comet Kohoutek 1973f at the time, from Hamburg Observatory in Germany. Comet Kohoutek would not pass perihelion until the following December at the very small heliocentric distance of 0.14 AU and was widely touted as being a potential "Comet of the Century" but, although becoming readily visible to the unaided eye, failed to live up to those projections. It was discussed in last week's "Special Topics" presentation and is a future "Comet of the Week."

MARCH 7, 2003: A team of Spanish astronomers led by Jose Luis Ortiz Moreno obtains the first discovery images of the large Kuiper Belt object, and "dwarf planet," now known as (136108) Haumea, although these images were not noticed and reported until almost 2 ½ years later. Michael Brown's team reported their discovery of Haumea very shortly thereafter, and there has been some unfortunate controversy as to which team deserves proper credit for its discovery. Haumea and the other "dwarf planets" in the Kuiper Belt are discussed in a future "Special Topics" presentation.

***THERE ARE NO CALENDAR ENTRIES FOR MARCH 4 AND 5.**

Replica of the Vega Solar System Probe Bus and Landing Apparatus at the Udvar-Hazy Center. Courtesy Smithsonian's National Air and Space Museum/ Dane Penland.

COMET OF THE WEEK: WEST 1975N

Perihelion: 1976 February 25.22, q = 0.197 AU

Photograph I took from White Sands National Monument of Comet West on the morning of March 3, 1976. This photo would appear on the front page of our local newspaper two days later.

What I consider to be the best comet I have ever seen was missed by most of the general public. Part of this was due to the fact that it put on its best appearance in the sleepy hours before dawn, but a large part of it was due to the fact that astronomers were still reeling a bit from the disappointing performance put on by Comet Kohoutek 1973f two years earlier. (I discuss this comet in last week's "Special Topics" presentation, and it is a future "Comet of the Week.") Furthermore, the initial projections did not suggest anything especially spectacular; instead, they suggested something more like the performance Comet Kohoutek actually achieved. (It's worth pointing out, however, that calculations soon began to indicate that, unlike Comet Kohoutek, Comet West was not a first-time visitor from the Oort Cloud.) Of course, comets can be unpredictable . . .

The comet was discovered in early November 1975 by Richard West at the European Southern Observatory's headquarters in Geneva, Switzerland, while he was examining a survey photograph taken on September 24 with the ESO's Schmidt telescope in Chile; it appeared as a faint trail, between 14th and 15th magnitude. He subsequently was able to identify the comet on several ESO Schmidt photographs extending back to August 10, and further was able to recover it on photographs taken a few days after he had noted the original images. The initial orbital calculations suggested it would be well placed for observations from the northern hemisphere the following March but, as I mentioned above, did not indicate it would be especially bright.

During the weeks after its discovery Comet West was primarily a southern hemisphere object, and it brightened steadily, to about 9th or 10th magnitude by the end of 1975, to about 6th magnitude in late January 1976, and to about 3rd or 4th magnitude, and exhibiting a one-degree-long-tail, in mid-February. The final pre-perihelion observations from the southern hemisphere were made around February 20 and indicated a brightness around 1st or 2nd magnitude, but by then the comet was deep in evening twilight.

Observations from the northern hemisphere became possible on the evening of February 21, when the comet was located 13 degrees due east of the sun. I was rather surprised that evening when I easily detected it in binoculars, and then with my unaided eye, as a bright object near magnitude -1, and with a short but bright dust tail, located low in the western sky during dusk. Over the next few days as the comet passed through perihelion it was located between Earth and the sun – and thus presented a large phase

Photograph of Comet West taken by my father, Nile Hale, from the front door of our residence in Alamogordo, New Mexico, on the morning of March 5, 1976.

angle, which in turn created a significant brightness enhancement from forward scattering of sunlight – and was visible telescopically during daylight (with at least one reported naked-eye sighting) with a brightness near magnitude -3.

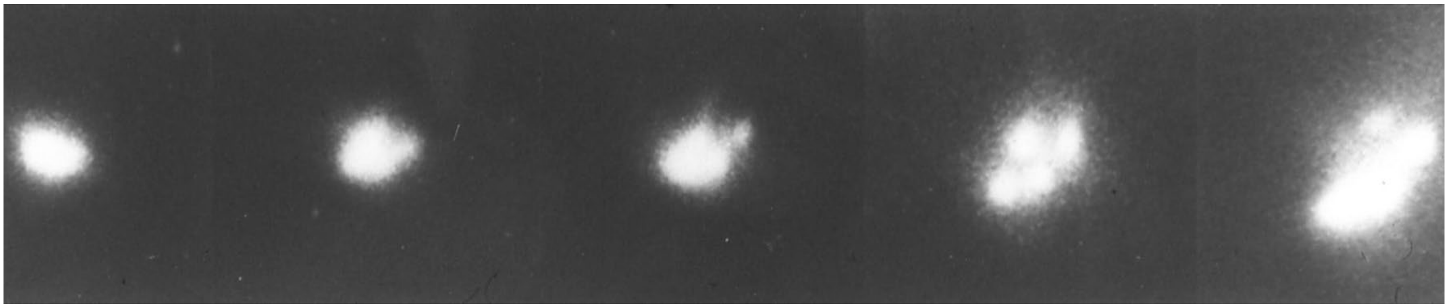
After being nearest Earth (0.79 AU) on February 29, Comet West moved over into the morning sky during the first week of March. I had my first morning-sky view of it (from White Sands National Monument – now White Sands National Park) on the morning of March 3, and was stunned to see it as a spectacular object near magnitude -1 with a bright dust tail which I measured as being 23 degrees long. Although the comet began fading afterwards, it also climbed higher into the morning sky, and for the next couple of weeks was an imposing sight during the pre-dawn hours with the dust tail – which exhibited several of the "synchronic bands" – being between 25 and 30 degrees in length.

Even by late March Comet West was still an easy naked-eye object of 4th magnitude – still with a tail 5 degrees long or longer – and it dropped below naked-eye visibility around mid-April. It had faded to 9th or 10th magnitude by early July and to 11th magnitude by the time the final visual observations were obtained during the latter part of August. The final photographs were taken in late September.

Beginning in early March observations with large telescopes began to indicate that the nucleus had split; initially there were two pieces, but within a few days two more fragments became apparent, arranged in somewhat of a "trapezium" shape. By the latter part of that month these individual nuclei were detectable visually in relatively small telescopes; one of these apparently dissipated by the end of the month, but the other three remained throughout the rest of the time the comet was followed. Calculations have indicated that the first splitting of the nucleus occurred on February 19, with the remaining fragmentation taking place over the following two weeks. These splitting events, which exposed significant amounts of previously-hidden ice to sunlight, were undoubtedly the primary cause of Comet West's dramatic upsurge in brightness around that time and of the dramatic display that I and others so fondly remember.

In addition to being the best comet I have ever seen, Comet West is important to me personally in some other ways as well. It put on its dramatic performance during the spring of my Senior year of High School – always an important time in one's life, and in fact I obtained an observation of it on the very night that I graduated. It played a major role in my Science Fair project that year, wherein I won a trip (as an alternate) to the International Science and Engineering Fair, and it also saw the first publications of my comet observations: I had submitted observation reports to both the IAU Circulars and to Sky & Telescope, and both of these publications published them.

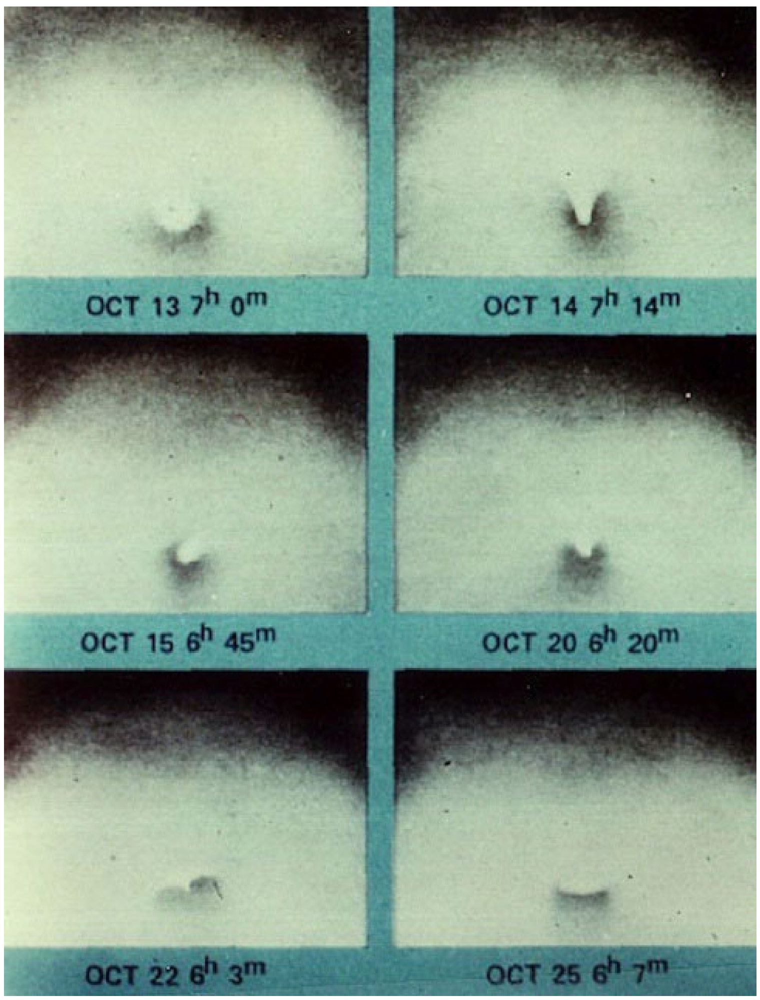
Comet West was also the very last comet that I observed before leaving my home in New Mexico and traveling to the U.S. Naval Academy, where I had been accepted. I obtained my final observation on the evening of July 3, and felt that it was carrying my childhood with it as it left for the depths of the outer solar system, while I would be journeying on to adulthood and whatever awaited me there.



Photographic sequence of the four split nuclei of Comet West spreading apart, obtained by Scott Murrell and Claude Knuckles with the 61-cm planetary telescope on Tortugas Mountain at New Mexico State University. The individual photographs (left to right) were obtained on March 8, 12, 14, 18, and 24, 1976. Photo courtesy Reta Beebe/ New Mexico State University/NASA

SPECIAL TOPIC: FRED WHIPPLE'S COMET MODEL

Once it had become clear that comets are bona fide members of the solar system just as planets and asteroids are, the question then becomes just what their physical nature might be. While they may appear to be fairly large in our nighttime sky, the fact that background stars shine through their tails and their comae undimmed indicates rather strongly that these are not solid but instead are mere clouds of material. Furthermore, while a comet that passes near a planet such as Jupiter will have its orbit strongly affected, the orbit of the planet itself is not affected by any measurable extent, indicating that a comet's mass is negligible compared to that of a planet. Astronomers of the 19th and early 20th Centuries who studied comets that were passing close to Earth were unable to detect any kind of solid object in or near the center of their comae, suggesting that any such object had to be small, no more than a couple of hundred km across.

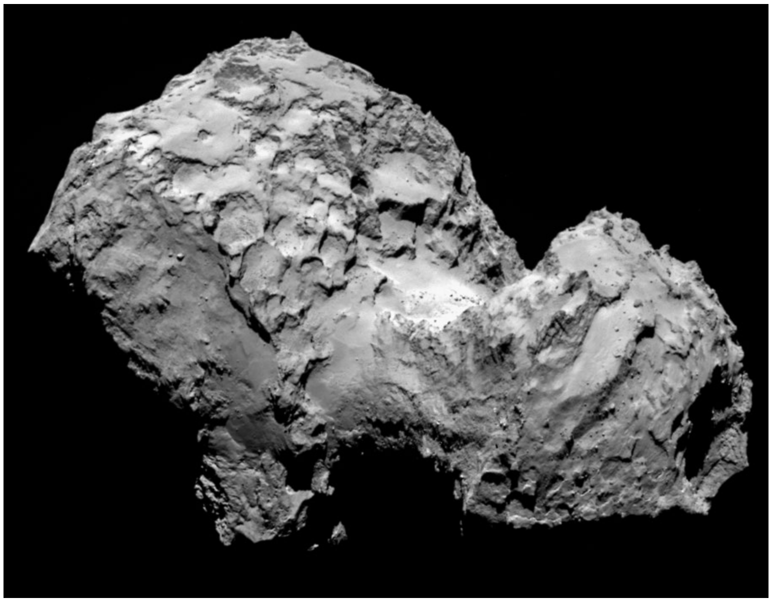


Sketches of the inner coma of Comet 1P/Halley, showing apparent "jets" of material, made by Friedrich Bessel during the comet's return in 1835.

Once spectroscopic observations of comets began to be made during the 1860s these revealed the presence of several gaseous substances, including those containing carbon atoms. Meanwhile, studies of cometary tails had revealed that one of their primary constituents is dust, a conclusion that was reinforced once the relationship between comets and meteor showers was established during the latter decades of the 19th Century.

As is true with any scientific model, any explanation of a comet's physical nature had to take all these various facts into account. One of the early widely accepted explanations of a comet was the so-called "flying sandbank" model developed in the 1880s by British astronomer Richard Proctor and championed most strongly in the early- to mid-20th Century by British astronomer Raymond Lyttleton. Within this model, comets are composed of a swarm of small solid dusty "objects," the largest perhaps being a few meters in diameter, which would contain the various gases absorbed within them. As this "sandbank" approaches the sun the heat from sunlight would cause the objects within it to release these gases, producing the cometary effects we see such as the coma and the tail. Eventually, after the comet has made numerous returns to perihelion, all the gas would be released, and the comet would be nothing except a swarm of dust particles and a few larger objects, perhaps to form part of a meteor shower should Earth ever intercept it in the future.

This "flying sandbank" model, despite being the dominant theory for the structure of cometary nuclei for much of the first half of the 20th Century, suffered from several serious difficulties. Clearly, a comet would lose a significant amount of gas with each perihelion passage, and consequently its "lifetime" before running out of gas would be relatively short. Several comets, however – including 2P/Encke, which returns every 3.3 years – were observed at return after return after return with their supplies of gas seeming to undergo little change. To get around this, the idea was introduced that the "swarm" would accumulate additional gas as it traveled through the solar system, however it soon became clear that comets lost far too much gas when near the sun to ever be replenished by what they might sweep up during the rest of their travels.

Spacecraft images of cometary nuclei. Left: Comet 103P/Hartley 2, as imaged by the EPOXI (formerly Deep Impact) mission on November 4, 2010. The nucleus exhibits jetting activity at both ends and an inactive plain in the center. Courtesy NASA. Right: Comet 67P/Churyumov-Gerasimenko on August 3, 2014, as imaged by ESA's Rosetta spacecraft. The comet is still over a year away from perihelion passage and thus is inactive for the most part. The "contact binary" structure is readily apparent. Courtesy ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/ IDA.

What would prove to be the "flying sandbank's" downfall, however, was a phenomenon first noticed in the 1820s by the German mathematician Johann Encke while studying observations of the comet that is named after him. Encke noted that, even after he allowed for all possible gravitational perturbations by the various planets, the comet was returning to perihelion a few hours earlier than predicted at each return. To account for this, Encke proposed a "resisting medium" in the solar system that was slowing the comet down and pushing it into a smaller orbit.

Throughout the remainder of the 19th Century a few other comets were seen to exhibit this phenomenon, which is now known under the name of "non-gravitational forces." Despite the fact that there were problems with the idea, Encke's idea of a "resisting medium" continued to hold for the most part . . . until the 1930s when two short-period comets were found to be accelerated into larger orbits – the exact opposite of what a "resisting medium" would do. While the "flying sandbank" model could be consistent with the effects of a "resisting medium," it fell apart completely when confronted with these observed accelerations. The time had come for a new model.

In a series of papers, the first of which was published in March 1950, Harvard University astronomer Fred Whipple – who had spent the previous two decades studying phenomena associated with meteors and who managed to discover six comets in the process – proposed what he initially called his "icy conglomerate" model for a comet's nucleus. In this model – which has come to be more popularly called the "dirty snowball" – a comet's nucleus is a solid object made up of ices of various volatile gases which in turn have large amounts of dust grains embedded within them. Under the heat of sunlight these ices "sublimate" – i.e., turn directly from a solid into a gas, as will happen in the near-vacuum environment of space – and in this process the gas along with the embedded dust grains is ejected off the nucleus into the coma. The sunlight also breaks apart the parent molecules of these sublimated ices – water ice as well as other ices such as carbon monoxide and carbon dioxide – into the daughter molecules that were being spectroscopically detected at the time.

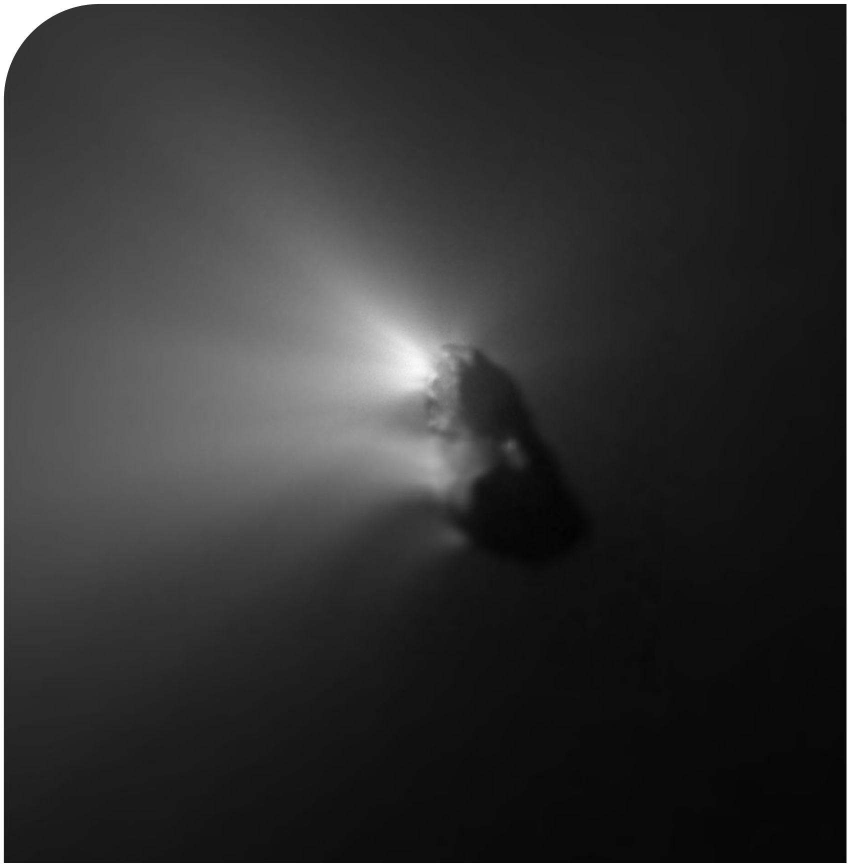
Non-gravitational forces can be accounted for in Whipple's "dirty snowball" via an explanation first proposed as far back as 1835 by the German astronomer Friedrich Bessel, who during his observations of the inner coma of Comet 1P/Halley during its return that year noticed "jets" appearing to come from the center of the coma. Bessel reasoned that these "jets" were made up of material being ejected away from the comet, and in accordance with Isaac Newton's Third Law of Motion – i.e., for every action there is an equal and opposite reaction – were pushing whatever was in the center in the opposite direction. In the face of the "resisting medium" Bessel's idea didn't gain much traction, but once Whipple's "dirty snowball" model was published it fit in very well. Bessel's "jets" were eruptions of the sublimated ices (and embedded dust grains) being ejected off the comet's nucleus, and in turn were acting as small rocket engines, pushing the nucleus in the opposite direction. Since these eruptions could take place in any direction, some would act to push the comet into a smaller orbit, while others would accelerate it into a larger one – precisely what is observed.

Any good scientific model should be able to predict as-yet-unobserved phenomena. Once radio telescope technology had progressed to the point where valid observations of comets could be made, water and other "parent molecule" ices began to be detected in cometary comae beginning in the mid-1970s. A decade earlier the German physicist Ludwig Biermann had pointed out that, if water is indeed a predominant parent molecule in a comet's nucleus, sunlight would break it apart into hydrogen and hydroxyl (OH), and the comet would be surrounded by a large cloud of hydrogen; this was first detected in early 1970 in the first comet observations ever made from space, of Comet Tago-Sato-Kosaka 1969g. (These observations were discussed in that comet's "Comet of the Week" presentation four weeks ago.) Meanwhile, in November 1980 MIT astronomer Paul Kamoun utilized the giant Arecibo radio telescope in Puerto Rico to obtain radar return echoes from the nucleus of Comet 2P/Encke, and similar radar return echoes were detected (with both Arecibo and the NASA Deep Space Network antenna at Goldstone, California) in May 1983 of the Earth-approaching long-period Comet IRAS-Araki-Alcock 1983d. (Both of these comets are future "Comets of the Week.") The radar echoes revealed, most importantly, that these cometary nuclei are solid objects, and are a few km in diameter.

The final verification of Whipple's "dirty snowball" came with the return of Comet 1P/Halley in 1986. The Soviet Union's Vega 1 and 2 spacecraft made somewhat distant flybys of Halley's nucleus in early March, and then the European Space Agency's Giotto mission passed just 600 km from the nucleus on March 14. The images taken by Giotto revealed an oblong, peanut-shaped object some 15 km long by 9 km wide, with several "jets" of material erupting from it, and on-site measurements made by Giotto and other spacecraft of the material in and around the nucleus were almost entirely consistent with what would be expected of Whipple's "dirty snowball." (The overall history of Comet 1P/Halley is the subject of next week's "Special Topics" presentation, and its 1986 return in particular is next week's "Comet of the Week.")

One perhaps surprising result from the Giotto images was the extreme blackness of Halley's nucleus. As it turns out, when the surface ice is sublimated some of the dust gets left behind, and over time some of this surface dust starts to form a "crust" over parts of the nucleus – in part, creating some of the inactive regions on the nucleus that are apparent in the images. Also, while a significant portion of the erupted dust grains are ejected from the nucleus altogether and go into their own respective orbits around the sun – and producing future meteor showers here on Earth in the process – a fraction of that dust rains back down onto the surface. Examination of cometary dust grains obtained in the upper atmosphere show that they are very dark – blacker than soot – and accordingly it is easy to see how a cometary nucleus coated with these particles would appear black. (The collection and study of these grains is covered in a future "Special Topics" presentation.)

Giotto also found that there is a significant amount of formaldehyde and other organic compounds within Halley's coma, material which obviously was erupted off the nucleus along with the other material. Detailed studies of various comets since then, both from Earth and from spacecraft missions, have revealed the presence of even more complex organic compounds, including various polymers, and have shown that they make up a non-trivial portion of a comet's mass. The presence of such substances has significant implications both in the study of the natural history of Earth and the other planets, and, conceivably, as a



Our first good look at a comet's nucleus. Comet 1P/Halley, as imaged by the European Space Agency's Giotto spacecraft on March 14, 1986. Courtesy ESA.

platform for resource extraction; these are discussed in future "Special Topics" presentations.

Since the 1986 return of Comet 1P/Halley several other spacecraft missions have visited comets, the most dramatic of these missions being the European Space Agency's Rosetta mission which orbited Comet 67P/Churyumov-Gerasimenko from 2014 to 2016 and deployed a lander, Philae, which although it was not as successful as had been hoped nevertheless was able to return some interesting results. As is perhaps to be expected, cometary nuclei are not all the same but instead seem to exhibit a variety of structural and compositional makeups, in some places being somewhat porous and in other places being very hard. 67P's nucleus is a "contact binary," a phenomenon that has been seen in several Earth-approaching asteroids, wherein two different objects collided and stuck together – becoming one object in the process – millions to billions of years ago. Several of these missions (including, certainly, Rosetta) and their destination comets are covered in future "Comets of the Week."

One type of object that we have not yet been able to examine in close detail with a spacecraft is a long-period comet; while we might expect similarities with a short-period comet, there should also be significant differences as well. Due to the long time necessary to plan a spacecraft mission, as well as the usually short lead time we have of a long-period comet's approach and the generally high orbital inclinations that they exhibit, it has not been really practical to put together such a mission – although with the current survey programs that are operational we do at least have a longer lead time nowadays. Last year ESA announced the initial development of a "Comet Interceptor" mission wherein a spacecraft would be launched and kept "in waiting" for the appearance of a suitable long-period comet. Comet Interceptor is among the planned spacecraft missions discussed in a future "Special Topics" presentation.

WHIPPLE'S SHIELD PROTECTED GIOTTI

When the Giotti spacecraft launched on its voyage to explore Halley's Comet in 1985, it was an invention by the son of an Iowa farmer decades earlier that allowed the mission to be successful.

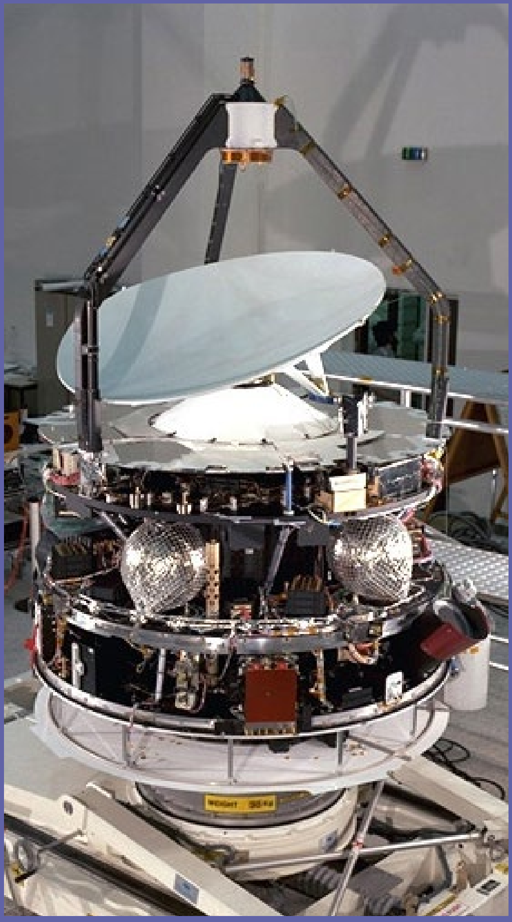
The most difficult problem of the mission to overcome was how to ensure that Giotto survived long enough to snap its close-up images of the comet nucleus while the spacecraft and the comet were heading towards each other at a combined speed of 245 000 km/hour (equivalent to crossing the Atlantic Ocean in 11 minutes!). At this speed, a 0.1-gram dust particle would be able to penetrate 8 cm of solid aluminium.

Since it was out of the question to equip Giotto with a 600-kg aluminium shield, engineers turned to a more subtle, 'sandwich' design first proposed by American astronomer Fred Whipple back in 1946 – long before the beginning of the Space Age.

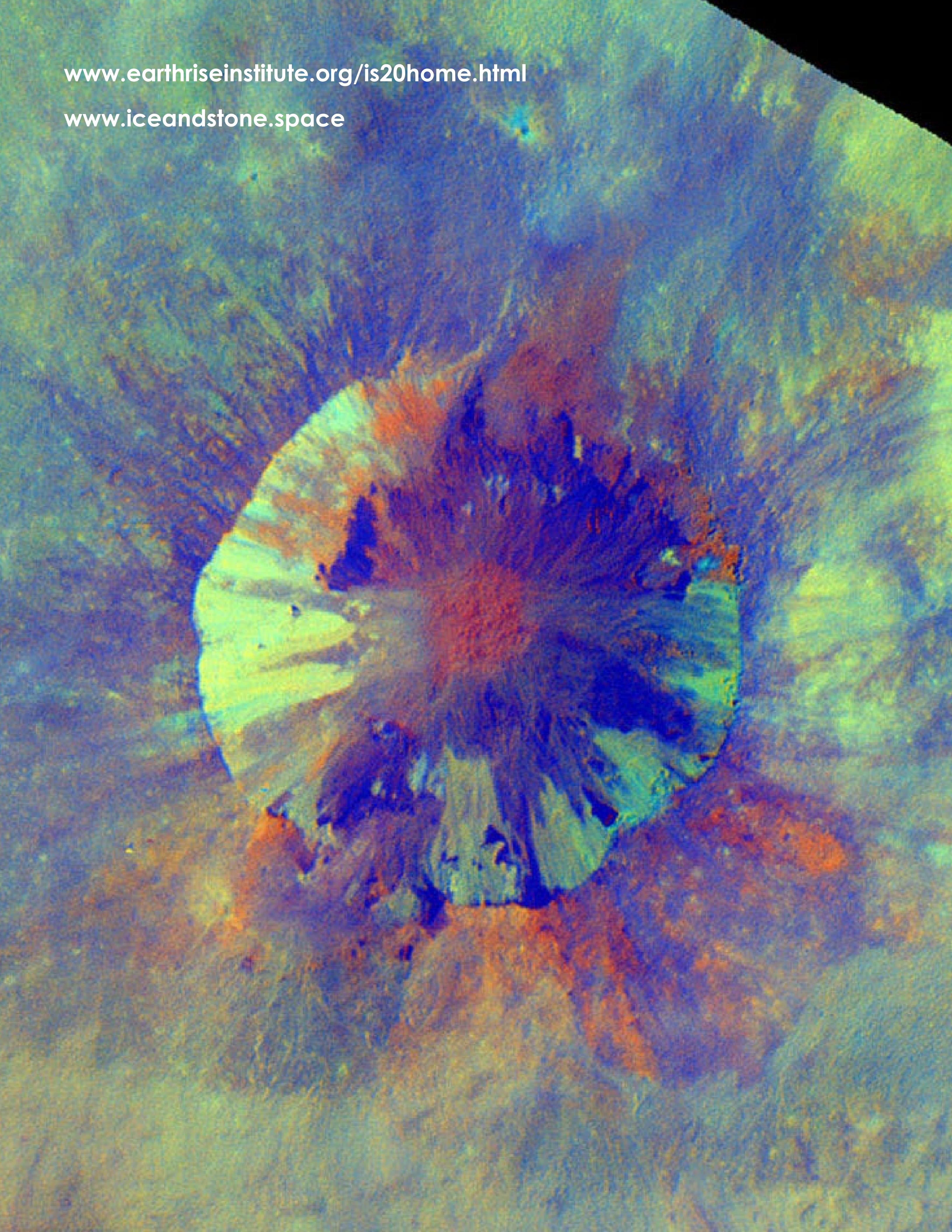
Whipple was born in Red Oak, Iowa in 1906. He earned his degrees in Mathematics and Astronomy. During WWII he invented a machine which was used to create tiny pieces of aluminum foil – chaffe – that were dropped from planes and confused radar. He followed that with his idea for a meteoroid bumper that would vapourise small particles upon impact.

Giotti's dust shield consisted of two protective sheets. At the front was a sheet of aluminium (1 mm thick), which would vapourise all but the largest of the incoming dust particles. A 12-mm thick sheet of Kevlar at the rear would absorb any debris that pierced the front barrier. Together they could withstand impacts from particles 1 gram in mass travelling 50 times faster than a bullet.

The ESA-led mission was not the only spacecraft to take advantage of Whipple's idea. The International Space Station uses a variety of Whipple Shields to protect it from impact damage.



Giotto during final testing at Intespace, Toulouse, France on Nov. 1, 1984 . Courtesy ESA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