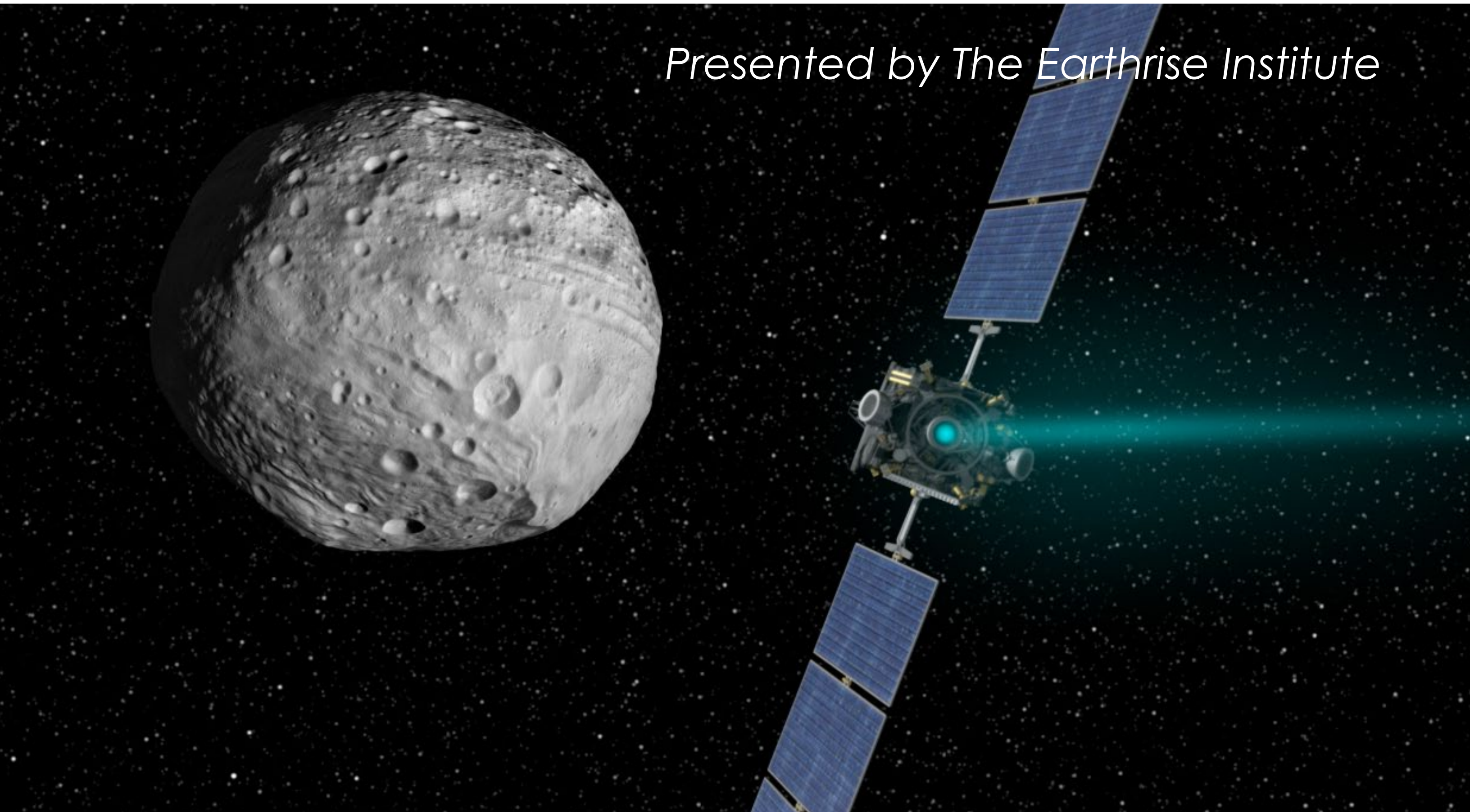
ICE & STONE 2020

Week 5: January 26-February 1, 2020

Presented by The Earthrise Institute



ABOUT ICE AND STONE 2020

It is my pleasure to welcome all educators, students, and anybody else who might be interested, to Ice and Stone 2020. This is an educational package I have put together to cover the so-called "small bodies" of the solar system, which in general means asteroids and comets, although this also includes the small moons of the various planets as well as meteors, meteorites, and interplanetary dust. Although these objects may be "small" compared to the planets of our solar system, they are nevertheless of high interest and importance for several reasons, including:

a) they are believed to be the "leftovers" from the formation of the solar system, so studying them provides valuable insights into our origins, including Earth and of life on Earth, including ourselves;

b) we have learned that this process isn't over yet, and that there are still objects out there that can impact Earth and threaten our existence upon it; and

c) we have also learned that many of these objects contain valuable resources that we can utilize here on Earth as well as in space, should humanity make the decision to expand out into the solar system.

Ice and Stone 2020 will cover various facets of our knowledge about these objects. I do not intend this to be a substitute for formal classroom educational courses, however I do intend this to supplement the material in such courses, and to act as a resource for additional information.

Throughout each week of 2020 Ice and Stone 2020 will unveil new "presentations" about different aspects of our solar system's "small bodies." Specifically, each week will feature:

a) "This Week in History" -- a brief summary of important events in the study of "small bodies" during that particular week in history. This will include such events as spacecraft encounters, asteroid flybys, important discoveries, and notable publications and announcements, each of which will include a short summary. Some of the events are those that will be taking place in the future.

b) "Comet of the Week" -- a short discussion of an important comet that was visible during that corresponding week in the past. These could be comets that were especially bright, or that are scientifically important in some way. A small number of these are comets that are expected to be visible during 2020 or in later years.

c) "Special Topic" -- each week will feature a moderately in-depth discussion of some topic related to the study of "small bodies." Some representative topics include: main-belt asteroids, near-Earth asteroids, "Great Comets," spacecraft visits (both past and future), meteorites, and "small bodies" in popular literature and music.

Throughout 2020 there will be various comets that are visible in our skies and various asteroids passing by Earth -- some of which are already known, some of which will be discovered "in the act" -- and there will also be various asteroids of the main asteroid belt that are visible as well as "occultations" of stars by various asteroids visible from certain locations on Earth's surface. Ice and Stone 2020 will make note of these occasions and appearances as they take place. The "Comet Resource Center" at the Earthrise web site contains information about the brighter comets that are visible in the sky at any given time and, for those who are interested, I will also occasionally share information about the goings-on in my life as I observe these comets.

I will make the assumption that Ice and Stone 2020 participants have some knowledge about basic astronomy, including knowledge about the various planets as well as basic astronomical terms like "magnitude." I will also assume that participants have -- or at least know where to find -- basic information about orbits, including terms like "perihelion" and "astronomical unit" (or "AU"). The term "q" that appears throughout various presentations refers to an object's perihelion distance from the sun, usually given in AU.

The Earthrise Institute is pleased to be partnering with various organizations in Ice and Stone 2020. We especially acknowledge RocketSTEM, which will be hosting our presentations and assist in putting together lesson plans around them. The Las Cumbres Observatory, a worldwide network of automated telescopes placed at some of the top observing sites in the world, will be available for participants who might wish to image some of the objects that are visible.

2020 marks some very special anniversaries for me. It was 50 years ago, on February 2, 1970, that I saw my very first comet -- which, coincidentally, also happened to be the first comet ever observed from space. And it was 25 years ago, on July 23, 1995, that I discovered the comet that brought me worldwide recognition and forever changed my life. As I begin to approach the later years of that life it is my intent with Ice and Stone 2020 to share both the knowledge and the joy that I have gained throughout that life with the future generations of humanity, all over the world, so that they can use that knowledge -- however they see fit to do so -- to build a worthy future.

Alan Hale

Founder, The Earthrise Institute

THIS WEEK IN HISTORY

JANUARY **26** 27 28 29 30 31 1

JANUARY 26, 1978: The International Ultraviolet Explorer (IUE) spacecraft is launched from Cape Canaveral, Florida. Throughout its 18 years of operations IUE conducted observations of many astronomical objects, including several comets.

26 JANUARY **27** 28 29 30 31 1

JANUARY 27, 2016: A team of astronomers led by Tabitha Boyajian of Yale University publishes their paper on the star KIC 8462852 – unofficially dubbed "Boyajian's Star" – based upon observations obtained by the Kepler spacecraft. The star had shown – and continues to show – large and irregular variations in brightness unlike those seen in any other star. Among the more likely explanations that have been proposed for these brightness variations is a large swarm of comets. The subject of exocomets, including those possibly orbiting KIC 8462852, is covered in this week's "Special Topics" presentation.

JANUARY 27, 2020: The main-belt asteroid (28758) 2000 HE10 will occult the 7th-magnitude star HD 50482 in Gemini. The predicted path of the occultation passes over central Greece (just north of Athens), far southern Albania, eastern and northern Italy (including Florence), central France, far southwestern England, southern Ireland, far southern Greenland, the central northern regions of Nunavut, the Northwest Territories, and Yukon in Canada, and southern Alaska.

COVER IMAGES CREDITS:

Front cover (top): Image of C/2014 Q2 (Lovejoy), a long-period comet discovered on 17 August 2014 by Terry Lovejoy. This photograph was taken from Tucson, Arizona, using a Sky-Watcher 100mm APO telescope and SBIG STL-11000M camera. Courtesy of John Vermette.

Front cover (bottom): Artist's impression of NASA's Dawn spacecraft arrival at the giant asteroid Vesta on July 15, 2011. Courtesy of NASA/JPL-Caltech

Back cover: Composite image taken by JAXA's Hayabusa-2 spacecraft just before touchdown on the Ryugu asteroid to collect a sample in 2019. Courtesy of JAXA, Chiba Institute of Technology, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Meiji University, University of Aizu, AIST)

26 27 **JANUARY 28** 29 30 31 1

JANUARY 28, 1661: A bright comet first observed six days later by Polish astronomer Johannes Hevelius passes through perihelion at a heliocentric distance of 0.513 AU. Three and a half centuries later this comet would be found to be identical to a comet now known as 153P/Ikeya-Zhang, which is a future "Comet of the Week."

JANUARY 28, 2019: A team led by Ko Arimatsu of the National Astronomical Observatory of Japan reports their discovery of a 2.6-km wide Kuiper Belt object by means of an occultation of a star detected by a network of two small telescopes. The Kuiper Belt is the subject of a future "Special Topics" presentation.

26 27 28 **JANUARY 29** 30 31 1

JANUARY 29, 2003: Comet Kudo-Fujikawa C/2002 X5 passes through perihelion at a heliocentric distance of 0.190 AU. Observations of the comet obtained when it was near perihelion by instruments aboard the SOlar and Heliospheric Observatory (SOHO) spacecraft helped establish a connection between comets in our solar system and exocomets, and have accordingly helped in understanding the processes by which planetary systems form. The subject of exocomets is covered in this week's "Special Topics" presentation.

26 27 28 29 **JANUARY 30** 31 1

JANUARY 30, 1931: The near-Earth asteroid (433) Eros passes 0.174 AU from Earth. Parallax observations obtained during this approach helped refine the exact size of an Astronomical Unit, which set the standard for this measurement for the next few decades. This and other studies of Eros were covered in last week's "Special Topics" presentation.

JANUARY 30, 1996: A Japanese amateur astronomer, Yuji Hyakutake, discovers a comet (designated C/1996 B2) that two months later would pass close to Earth and become one of the brightest and most spectacular comets of the latter 20th Century. Comet Hyakutake is a future "Comet of the Week."

JANUARY 30, 2008: The tiny asteroid 2007 WD5, approximately 50 meters in diameter and discovered on November 20, 2007 by Andrea Boattini during the course of the Catalina Sky Survey based in Arizona, passes extremely close to Mars. The exact "miss distance" is uncertain but the most likely value is around 0.00015 AU (6.5 Mars radii). It has not been seen since.

JANUARY 30, 2020: The infrared-sensitive Spitzer Space Telescope, launched in 2003, is expected to be deactivated. Among its many studies, Spitzer has taken infrared images of numerous comets, some of which are featured in various presentations of "Ice and Stone 2020."

26 27 28 29 30 **JANUARY 31** 1

JANUARY 31, 1786: Comet 2P/Encke, discovered two weeks earlier, makes its first known passage through perihelion at a heliocentric distance of 0.336 AU. It will be making a return later this year and is a future "Comet of the Week."

JANUARY 31, 2020: The main-belt asteroid (198) Ampella will occult the 7th-magnitude star HD 59150 in Gemini. The predicted path of the occultation crosses the southern and central U.S. from southeastern Georgia to northern California and central Honshu in Japan.

JANUARY 31, 2026: NASA's Psyche mission, currently scheduled for launch in August 2022, is expected to arrive at its destination, the main-belt asteroid (16) Psyche. The Psyche mission is among those that will be discussed in a future "Special Topics" presentation on upcoming missions, while Psyche itself, which has a high metallic content, is discussed in a future "Special Topics" presentation on asteroid mining. (16) Psyche will be at opposition late this year and should reach 9th magnitude around that time.

26 27 28 29 30 31 **FEBRUARY 1**

FEBRUARY 1, 1981: Italian astronomers Andrea Carusi and Giovanni Valsecchi publish a paper describing how comets can be temporarily captured as satellites of Jupiter. Their primary example is Comet 82P/Gehrels 3, which had been such a satellite between 1967 and 1973 (prior to its discovery in 1975) and which will be a temporary satellite of Jupiter again for a few years around 2060.

FEBRUARY 1, 1994: Several U.S. Defense Department satellites detect a bright airburst explosion near the southwestern Pacific Ocean island of Kusaie, which was caused by a small impacting asteroid. Two fishermen on the ground witnessed the bright fireball. This event, which allegedly caused then-U.S. President Bill Clinton to be woken up by his Defense staff, and other similar events are discussed in a future "Special Topics" presentation.

FEBRUARY 1, 2002: Japanese amateur astronomer Kaoru Ikeya and Chinese amateur astronomer Daqing Zhang independently discover a comet which becomes moderately conspicuous to the unaided eye two months later. Comet Ikeya-Zhang was found to be identical to a comet observed in 1661 by the Polish astronomer Johannes Hevelius, and becomes the longest-period comet to be observed on two different returns. Now known as Comet 153P/Ikeya-Zhang, it is a future "Comet of the Week."

COMET OF THE WEEK: DAYLIGHT COMET OF 1910

Perihelion: 1920 January 17.59, q = 0.129 AU

Photograph of the Daylight Comet taken from Stockholm on January 28, 1910.

In early 1910 the entire world – astronomers and lay public alike – awaited the imminent return of Comet 1P/Halley, which had been recovered the previous September and which was already detectable with moderate-sized telescopes. While Halley would go on to put on a spectacular display around the time of its perihelion passage in April, it was upstaged early in the year by this brilliant comet which approached Earth from the far side of the sun. It didn't receive the names of any discoverers but instead is usually referred to as the "Daylight Comet of 1910" or as the "Great January Comet;" its formal designations are 1910a and 1910 I (old style) and C/1910 A1 (new style).

The comet was apparently first spotted on the morning of January 12 by miners at the Transvaal Premier Diamond Mine in South Africa, who spotted it in bright twilight as an object of magnitude -1 and with a distinct tail. Other workers spotted it on subsequent mornings, and after receiving word from the editor of a local newspaper Robert Innes, the

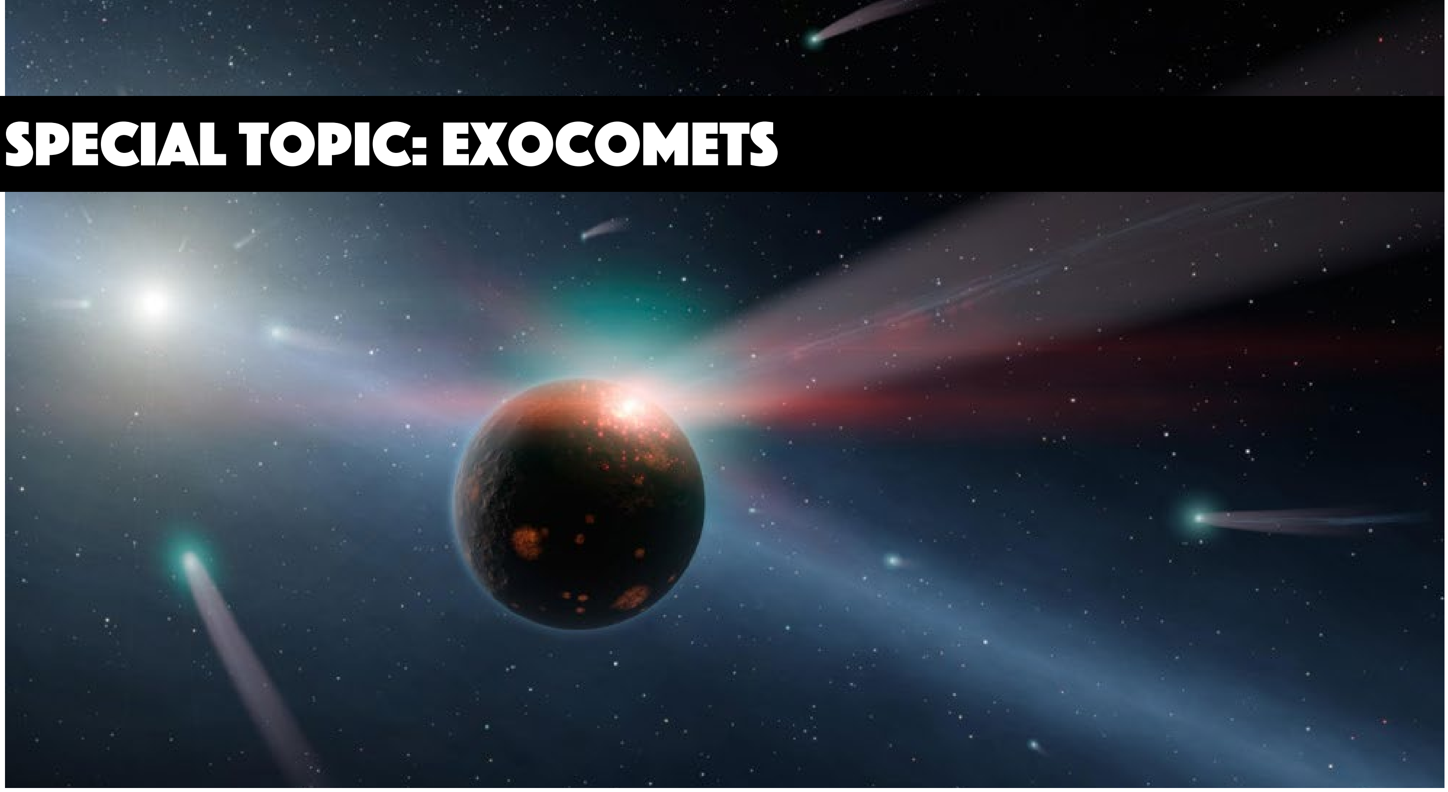
Director of the Transvaal Observatory, successfully observed it on the morning of the 17th.

From the 17th through the 19th the comet was widely observed some 3 ½ degrees from the sun as a brilliant object of magnitude -4 to -5 and plainly visible to the unaided eye during broad daylight. By the evening of the 20th it was starting to become visible in evening twilight from the northern hemisphere, and was described as being "as bright as Venus" with a tail some ten degrees long (although both twilight and light from the full moon may have shortened the visible tail length). As the comet climbed higher in the evening sky on subsequent nights (and as the moon cleared out from the evening sky) it began fading, but at the same time the visible tail length increased dramatically, to as long as 45 to 50 degrees by late January and the beginning of February. This tail exhibited a distinct curvature near its end – being "shaped like a curved horn" according to some accounts – and this was apparently due to "synchronic bands" which in turn indicated a large presence of dust in the comet. Spectra of the comet, including some obtained in daylight when it was near perihelion, also indicated a high dust content.

The comet had faded to 1st or 2nd magnitude by late January and to 3rd magnitude by early February. It was never far from the sun, being at a maximum elongation of 22 degrees at the end of the first week of February, and by the middle of that month had dropped below naked-eye visibility. After being in conjunction with the sun late that month it emerged into the morning sky in early March near 8th magnitude and faded steadily from that point, with the final observations being obtained in mid-July. By the time all this was going on, certainly, the world's attention was being devoted to the second, and more widely anticipated, of 1910's Great Comets (which, among other things, is the subject of a future "Special Topics" presentation).

Photograph of the Daylight Comet taken from Lowell Observatory in Arizona on January 29, 1910. The "synchronic bands" in the dust tail are obvious.

SPECIAL TOPIC: EXOCOMETS



Artist's conception of the putative cloud of comets surrounding Eta Corvi. Courtesy NASA/JPL-CalTech.

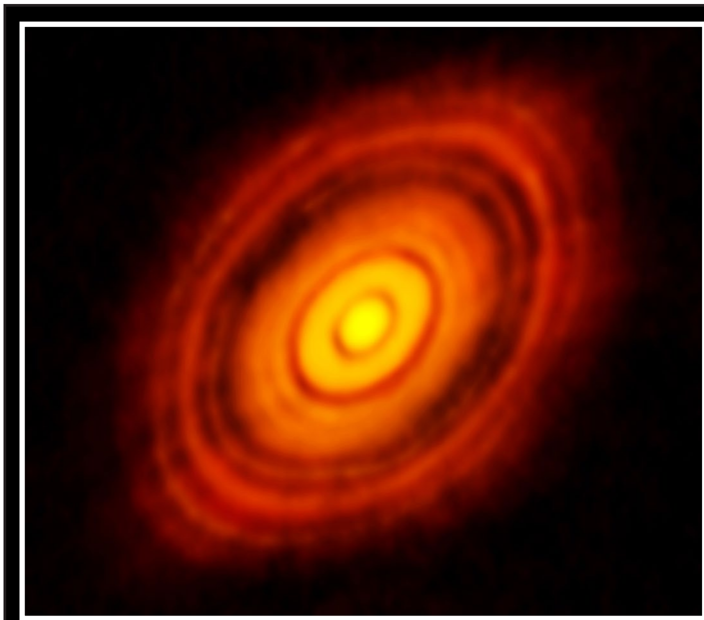
It is now generally accepted that the planets in our solar system formed via the accumulation of smaller bodies dubbed "planetesimals" – which in turn formed from the accumulation of dust grains and (in the outer and thus colder regions) gas molecules – early in its history. Due to the early sun's rotation the infalling material from the original cloud of gas and dust from which the sun formed would have been spun out into a relatively flat disk surrounding the sun, and thus the planets formed more-or-less in or at least near the plane of the sun's equator. Meanwhile, the asteroids and comets that we see today are the "leftovers" from the planet formation process, and the occasional impacts that take place serve to remind us that this process is still ongoing (albeit at a much lower level than early in the solar system's history). This entire process is discussed in more detail in a future "Special Topics" presentation.

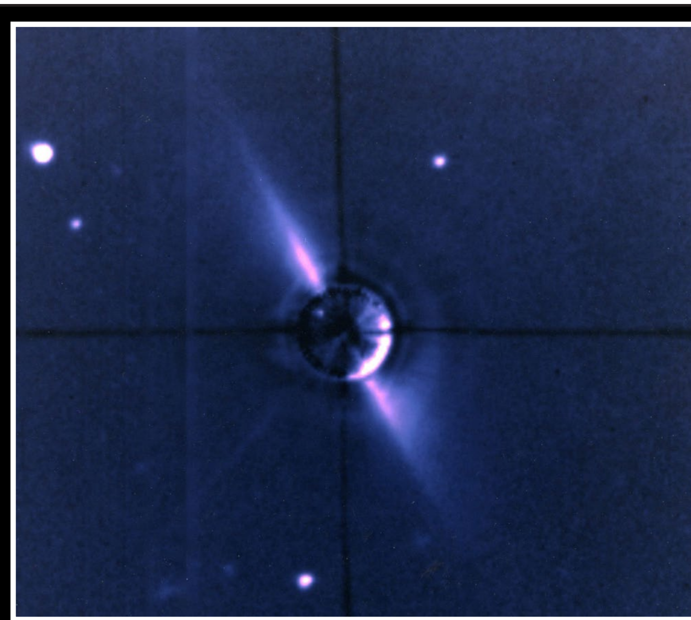
It would seem reasonable to suppose that the same processes would take place in the formation of other planetary systems. At this time well over 3000 planets have been confirmed orbiting around other stars – the vast majority of these having been detected by the Kepler Space Telescope that was launched in 2009 – and it is now quite apparent that planetary systems are indeed commonplace in the Galaxy (and, by extension, the universe as a whole), although it is also quite apparent that not only is our solar system not a "typical" planetary system, there really is no such thing as a "typical" planetary system.

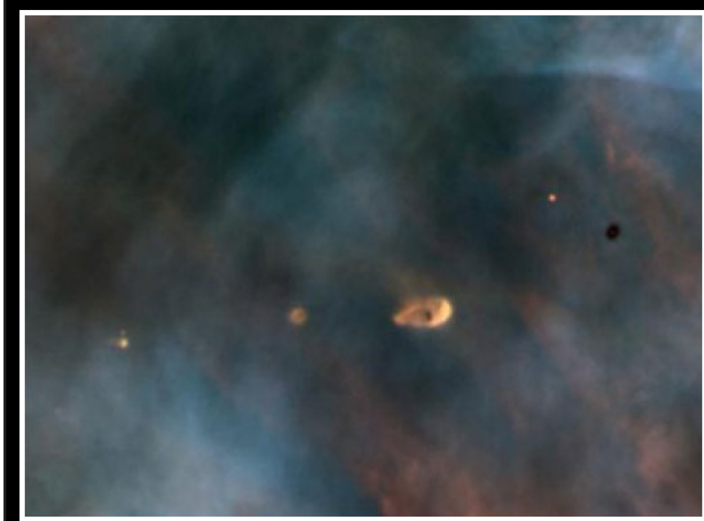
We would accordingly expect that young stars would be accompanied by disks of material that is currently in the act of forming planets. One of the earlier indications of this was the detection in 1975 by University of California astronomer Martin Cohen, who detected the infrared signature of the likely strong presence of water ice surrounding the young solar-type star HL Tauri (which is only about one million years old). The presence of a gas disk around HL Tauri was firmly detected at radio wavelengths by Annelia Sargent and Steve Beckwith in the mid-1980s, and has been imaged recently by the Atacama Large Millimeter/submillimeter Array (ALMA) telescope in Chile.

In 1983 the InfraRed Astronomical Satellite (IRAS) spacecraft detected excesses of infrared radiation, indicative of accompanying dust disks, around several stars, including the bright naked-eye stars Vega and Fomalhaut as well as the 4th-magnitude star Beta Pictoris. Begin in the mid-1990s the Hubble Space Telescope began directly detecting "proto-planetary disks" around young stars in the Orion Nebula region and elsewhere, and as of now planet-forming disks have been found around many young stars – including some with planets that have already formed – confirming the overall current consensus of the planet formation process.

The disk around Beta Pictoris, in particular, has been intensely studied ever since it was first reported. Following the IRAS report of excess infrared radiation, in 1984 Brad Smith and Richard Terrile optically imaged the disk with the 2.5-meter du Pont telescope (and an accompanying coronagraph) at the Las Campanas Observatory in Chile, finding it to be oriented almost exactly edge-on to us. Various studies over the years have shown that the disk is warped in places, suggesting the presence of planets, and in 2008 the presence of a planet roughly two to four times the







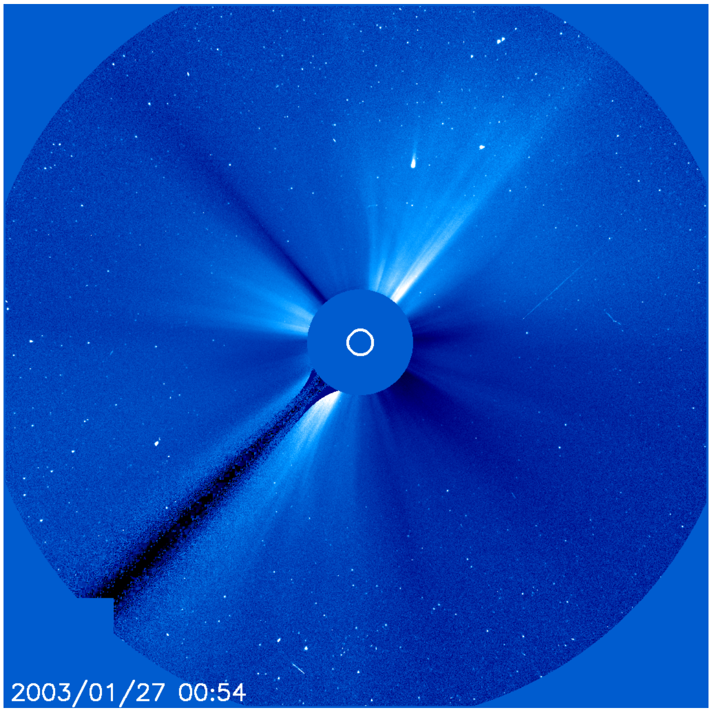
Planet-forming disks around other stars. Top Left: ALMA image of the disk around HL Tauri. Courtesy ALMA (European Southern Observatory/National Astronomical Observatory of Japan/National Radio Astronomy Observatory). Top Right: Optical image of the disk around Beta Pictoris, obtained by Brad Smith and Richard Terrile at Las Campanas Observatory in Chile. Courtesy Richard Terrile. Bottom Left: Hubble Space Telescope image of proto-planetary disks accompanying young stars in the Orion Nebula (M42). Courtesy C. Robert O'Dell/Rice University/NASA.

size of Jupiter was detected orbiting the star at an approximate distance of 9 AU.

In the mid-1980s a team of French astronomers, including Roger Ferlet, Anne-Marie Lagrange (who would make the discovery of Beta Pictoris' planet two decades later), and Alfred Vidal-Madjar reported spectroscopic observations of Beta Pictoris which indicated the presence of material falling onto the star, which they interpreted as being potentially due to comets. Similar phenomena have now been detected around a handful of other stars, including the 4th-magnitude star Eta Corvi, and meanwhile excess emission of carbon monoxide around the 6th-magnitude star 49 Ceti has been interpreted as being due to the presence of large numbers of comets in what would be that star's equivalent of the Kuiper Belt. More recently, observations obtained by ALMA – while it was still under construction – have revealed a large region in that star's surrounding disk where objects, including comets, are forming and growing.

Almost all of the known examples of these putative exocomet populations are young stars of early spectral type (mostly A-type, although Eta Corvi is an F-type star), however in 2001 a team led by Gary Melnick detected evidence of potential comets around the old, evolved star CW Leonis. In late 2003 astronomers Matthew Povich and John Raymond (at the Harvard-Smithsonian Center for Astrophysics) combined the available information for the potential exocomets known at that time (including those around CW Leonis) with information collected by instruments aboard the SOlar and Heliospheric Observatory (SOHO) of Comet Kudo-Fujikawa C/2002 X5 that had passed perihelion close to the sun early that year, and concluded that comets likely exist around almost all stars and play the same role in planet formation that they do in our solar system. (Incidentally, I along with my then-10-year-old son Tyler provided some of the early astrometric observations that were utilized in determining the orbit of Comet Kudo-Fujikawa.)

Although all of this evidence is interesting and



LASCO C3 image from SOHO of Comet Kudo-Fujikawa C/2002 X5 on January 27, 2003. The sun is hidden behind the central coronagraph. Courtesy NASA/ESA.

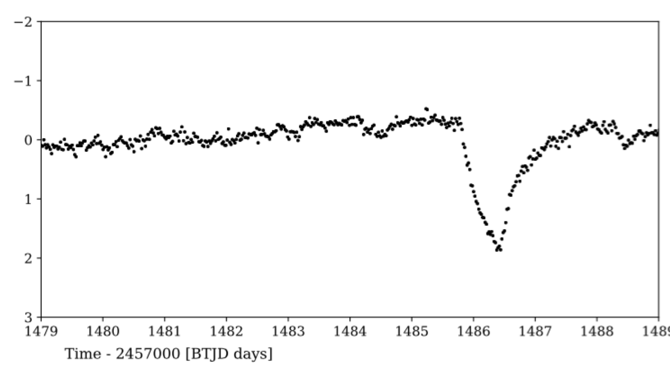
indicates the very likely existence of exocomets, it nevertheless remains circumstantial. In March 2019, however, a team of astronomers led by Sebastian Zieba and Konstanze Zwintz of the University of Innsbruck in Austria announced that in four months worth of photometric data taken by the recently-launched Transiting Exoplanet Survey Satellite (TESS) mission they had detected three drops in brightness that were consistent with the transits of exocomets across the disk of Beta Pictoris. The strongest of these brightness drops, which began on January 2, 2019, lasted two days and exhibited a behavior consistent with "an evaporating comet with an extended tail." These observations constitute the first confirmed detections of exocomets.

It would appear, then, that comets – and, one would think, asteroids – form and build planets in other planetary systems just like in our solar system, and that the existence of exocomets (and "exoasteroids") is ubiquitous throughout the Galaxy. Meanwhile, disks of material, which can perhaps be interpreted as being analogous to structures like the asteroid belt and Kuiper Belt in our solar system, have now been detected around many other stars. One nearby example is Epsilon Eridani, one of the closest sun-like stars to our solar system (being at a distance of 10.5 light-years); at least two such disks, one at approximately 3 AU from the star and the other at 20 AU, have been detected.

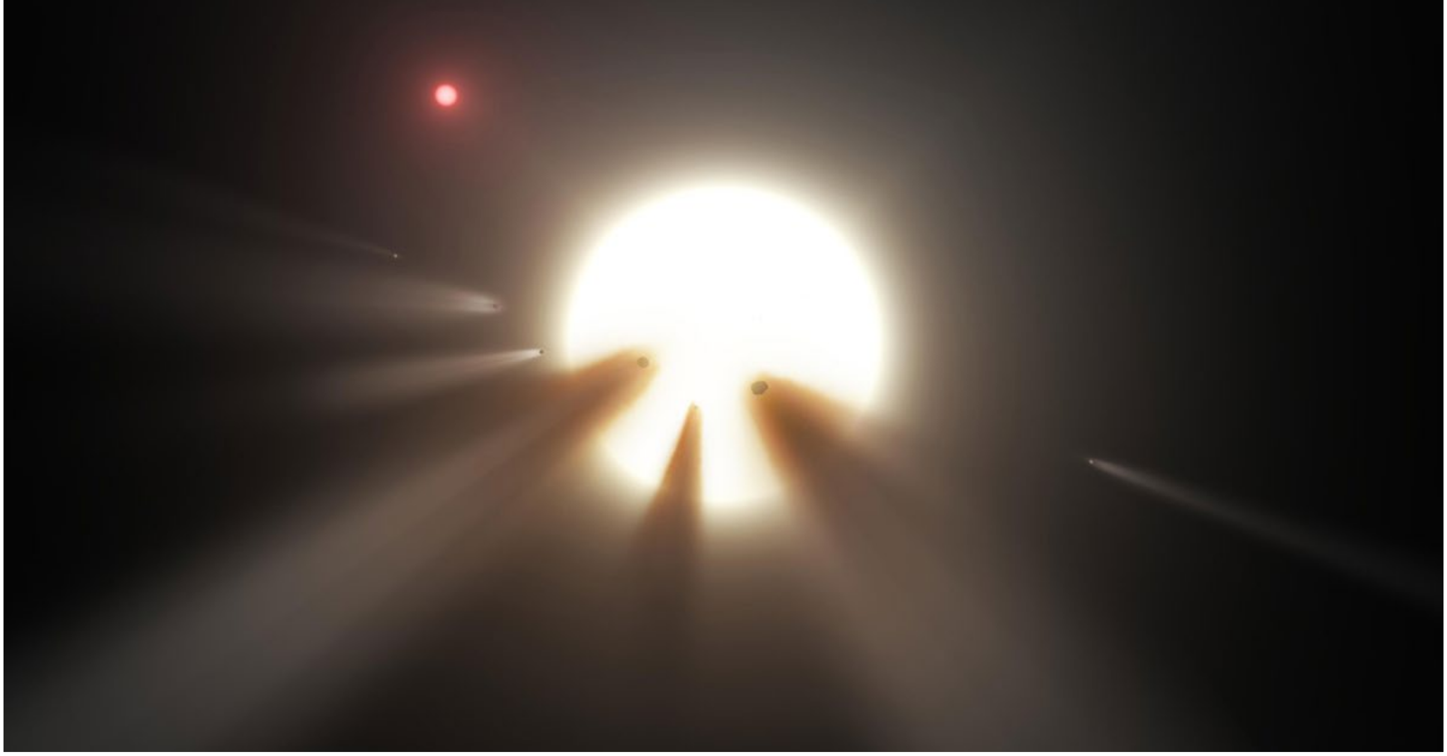
Since numerous comets would have been ejected from the solar system during the formation of the planets, and, as a result of gravitational perturbations from those planets, afterwards – a process that continues today – it would seem reasonable to think that comets would have been ejected from other planetary systems as well and are roaming interstellar space. Every once in a while one or more of these "interstellar comets" would accordingly be expected to pass through our solar system. The apparent first-known such object, named 'Oumuamua, was discovered in October 2017, and is featured in a future "Special Topics" presentation, while the second, and most recently-discovered, interstellar object, Comet 2I/Borisov, is currently detectable with large telescopes from the southern hemisphere and is a future "Comet of the Week."

An interesting variation of the subject of exocomets is provided by a 12th-magnitude star in Cygnus officially designated KIC 8462852 (the "KIC" standing for "Kepler Input Catalog") and informally known as "Boyajian's Star." It is located approximately 1470 light-years away and was one of the stars routinely examined by the Kepler Space Telescope while it was operational between 2009 and 2013. Kepler's primary mission was to examine stars for regular and periodic tiny drops in brightness that would be indicative of orbiting planets, but in the case of this star Kepler detected significantly large drops in brightness that occurred at irregular intervals, varied dramatically in strength, and lasted much longer – in one case, for as long as two months. An analysis of archived images of the star dating back to 1890 suggests that it has faded by as much as 15% during the intervening decades.

A team of astronomers that included several "citizen scientists" and led by Tabitha Boyajian (then at Yale University) announced their discovery of these light variations in a paper posted as a preprint in September 2015 and formally published (in the Monthly Notices of the Royal Astronomical Society) in late January 2016. The announcement became public with quite a bit of fanfare in October 2015 and was accompanied by a wide range of speculations



Graph of brightness of Beta Pictoris recorded by TESS, with the dip – occurring on January 2, 2019 – indicating the strongest of the recorded transits by an exocomet. This was the first confirmation of the existence of an exocomet. From Zieba et al. (2019).



Artist's conception of the putative "swarm" of comets accompanying KIC 8462852. Courtesy NASA/JPL-CalTech.

concerning possible causes of the star's seemingly inexplicable behavior. The potential explanation that received the most public attention involved "alien megastructures," i.e., all or portions of a hypothetical "Dyson Sphere," although the explanation that the researchers considered most likely invoked a large swarm of disintegrating comets – perhaps gravitationally distorted by a nearby M-dwarf star.

Boyajian's Star has continued to exhibit significant and irregular changes in brightness since the original announcement, including as recently as September 2019, and it continues to be monitored. As for the potential explanations, SETI searches for radio signals have been unsuccessful – not that the "alien megastructures" possibility was ever considered to be very likely in the first place. The "swarm of comets" possibility does have some difficulties – the existence of a comet cloud large and dense enough to cause the observed brightness drops being among them – but still remains a viable possibility. Similar explanations, for example, a large planet accompanied by one or more large populations of Trojan asteroids – a subject that will be discussed in a future "Special Topics" presentation – also remain viable. On the other hand, it is possible that intrinsic changes in the star's interior are responsible for the brightness variations. For now, there is no firm explanation for what is causing Boyajian's Star to exhibit the behavior we are seeing – but the resolution of such mysteries is why we conduct science in the first place.

Indeed, just a few months ago retired University of Nebraska-Lincoln astronomer Edward Schmidt published the results of his study wherein he has identified as many as 21 potential analogs of

Digitized Sky Survey image (8x8 arcminutes) of the star field surrounding KIC 8462852, aka "Boyajian's Star" (in center). Courtesy Association of Universities for Research in Astronomy (AURA).

Boyajian's Star. Some of these are one solar-mass stars similar to our sun, others are stars of two solar masses that are in or near the "red giant" phase of stellar evolution; meanwhile, some of these have drops in brightness with the approximate frequency that Boyajian's Star experiences, while others do so more rapidly. Whether or not these stars are exhibiting the same phenomena as Boyajian's Star, or there are other unknown explanations for their respective behaviors, remains to be determined.

www.earthriseinstitute.org/is20home.html

www.iceandstone.space