ICE & STONE 2020

WEEK 52: DECEMBER 20-26

Presented by The Earthrise Institute

#52

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THIS WEEK IN HISTORY

DECEMBER 20 21 22 23 24 25 26

DECEMBER 20, 1900: Michel Giacobini at Nice Observatory in France discovers the comet now known as Comet 21P/Giacobini-Zinner. This is the parent comet of the Draconid meteor shower and is also the first comet to be visited by a spacecraft; it is a previous "Comet of the Week."

20 **DECEMBER 21** 22 23 24 25 26

DECEMBER 21, 1969: Comet Tago-Sato-Kosaka 1969g passes through perihelion at a heliocentric distance of 0.473 AU. In early 1970 it became the first comet to be observed from space, and three weeks later became the first comet I ever observed. It is a previous "Comet of the Week."

DECEMBER 21, 1984: The Soviet Union's Vega 2 mission is launched from the Baikonur Cosmodrome in present-day Kazakhstan. In June 1985 Vega 2 flew by Venus, deploying a landing probe and an atmospheric balloon in the process, and in March 1986 it passed by Comet 1P/Halley, taking some of the first direct images of a cometary nucleus. The 1986 return of Comet Halley is a previous "Comet of the Week," and that presentation discusses the results of the various spacecraft missions to it.

DECEMBER 21, 1984: Brad Smith and Richard Terrile report their optical detection of an edge-on disk of material around the star Beta Pictoris. This was the first optical detection of a planet-forming disk around a star; detailed studies since then have revealed structure within the disk indicative of planetary formation, the existence of at least two planets, and the presence of "exocomets" falling into the star. The significance of such disks is the subject of this week's "Special Topics" presentation, and exocomets are the subject of a previous "Special Topics" presentation.

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

DECEMBER 22

DECEMBER 22, 1983: The International Sun-Earth Explorer 3 (ISEE-3) spacecraft passes just 120 km above the moon's surface, the fifth and last of a series of lunar flybys that direct it on a course – under the new mission name International Cometary Explorer (ICE) – towards an encounter with Comet 21P/Giacobini-Zinner in 1985, becoming the first spacecraft to visit a comet. The ICE mission is discussed in Comet 21P's "Comet of the Week" presentation and in a previous "Special Topics" presentation.

DECEMBER 22, 1996: Shane Stezelberger at the Goddard Space Flight Center in Maryland discovers a comet, now known as Comet SOHO C/1996 Y1, in images taken with the LASCO coronagraphs aboard the NASA/ESA SOlar and Heliospheric Observatory (SOHO) spacecraft. This was the first bright Kreutz sungrazer to be discovered in SOHO coronagraph images; it and other such comets are discussed in the "Comet of the Week" presentation for two other bright SOHO sungrazers, C/1998 K10 and C/1998 K11.

DECEMBER 22, 2000: French astronomers Christian Veillet and Alain Doressoundiram discover a moon accompanying the Kuiper Belt object 1998 WW31. With the exception of Pluto's moon Charon, this was the first moon to be discovered around an object in the Kuiper Belt. The Kuiper Belt is the subject of a previous "Special Topics" presentation.

DECEMBER 25

DECEMBER 25, 1758: German amateur astronomer Johann Palitzsch recovers the comet now known as Comet 1P/Halley, in accordance with the prediction made by the British astronomer Edmond Halley in the early 18th Century. This was the first recovery of a predicted return of a periodic comet, and firmly established that comets are members of the solar system. The story of Comet Halley is the subject of a previous "Special Topics" presentation.

DECEMBER 26

DECEMBER 26, 1908: Comet Morehouse 1908c passes through perihelion at a heliocentric distance of 0.945 AU. This was an unusually active comet with an unusual chemical composition, and is discussed (and pictured) in a previous "Special Topics" presentation.

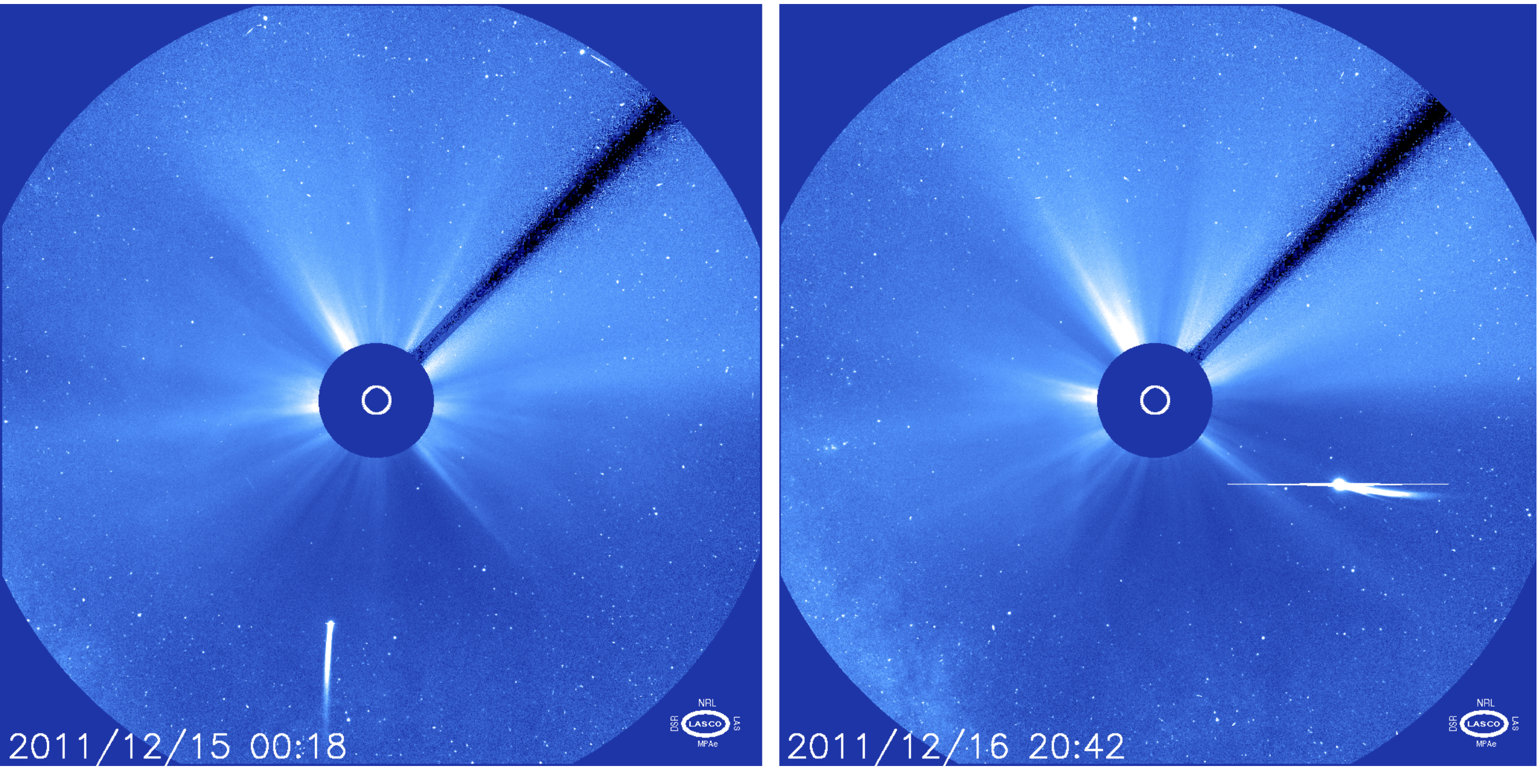
COMET OF THE WEEK: LOVEJOY C/2011 W3

Perihelion: 2011 December 16.08, q = 0.006 AU

Comet Lovejoy on the morning of December 21, 2011, from Cape Schanck, Victoria. Courtesy Paul Albers.

In the "Special Topics" presentation on Kreutz sungrazers eight weeks ago I mentioned that in 2007 Zdenek Sekanina and Paul Chodas published a paper wherein they predicted that a new "cluster" of sungrazers should be arriving within the next few decades, with "its earliest member possibly just several years from now." A little over four years later an amateur astronomer in Queensland, Terry Lovejoy, photographically discovered a 13th-magnitude comet that was soon found to be traveling on an orbit typical of Kreutz sungrazers. This was the first such object to be discovered from the ground in over four decades.

The comet brightened steadily as it approached perihelion, and was around 11th magnitude, and exhibiting a distinct tail, near the end of the first week of December, although shortly thereafter it disappeared into morning twilight. It appeared in the field-of-view of the LASCO C3 coronagraph aboard



LASCO C3 images from the SOHO spacecraft of Comet Lovejoy before and after perihelion passage. Left: December 15, 2011, a little over 25 hours before perihelion. Right: December 16, 2011, slightly less than 19 hours after perihelion. The intact comet with its bright new tail is in the lower right, while a ghostly remnant of its former tail can be seen hanging from the lower left side of the occulting disk. Both images courtesy NASA/ESA.

the SOlar and Heliospheric Observatory (SOHO) spacecraft on December 14, already brighter than any previous sungrazer had appeared in LASCO images, although a lot of uncertainty remained as to whether or not it would survive perihelion passage. After perihelion, however, it re-emerged intact from behind the coronagraph's occulting disk, and was already in the process of growing a new tail, having shed its old one as it rounded the sun. Around this time it was observed by several sun-studying spacecraft, including NASA's Solar Dynamics Observatory (SDO) and JAXA's Hinode probe, many of these observations being unique in the history of cometary astronomy. A handful of observers around the world succeeded in viewing the comet during daytime as an object of around magnitude -2.

Comet Lovejoy as photographed from the International Space Station on December 26, 2011, by Expedition 30 Commander Dan Burbank. Courtesy NASA.

By around the morning of the 19th observers in the southern hemisphere began reporting observations of Comet Lovejoy in twilight, with a brightness close to magnitude 0. Within a couple of days it started to become visible in a dark sky, as a spectacular object with a bright, long dust tail in excess of 30 degrees. It faded fairly rapidly, from about 2nd magnitude on December 21 to around 4th magnitude by December 24 and to between 5th and 6th magnitude by the end of 2011.

By this time observers were noting that there was little in the way of an actual coma on Comet Lovejoy, and in fact its appearance began to bear a rather strong resemblance to the "headless wonder" Kreutz sungrazer of January 1887 (discussed in the "Special Topics" presentation on Kreutz sungrazers). From the available data Zdenek

The tail of Comet Lovejoy on January 6, 2012. The "pointer" stars, Alpha and Beta Centauri, along with the Southern Cross and the Coalsack nebula, are on the left, and the Large Magellanic Cloud (partially hidden behind a tree) is on the right. Courtesy Justin Tilbrook in South Australia.

Sekanina concluded that the nucleus had indeed disintegrated, this event having taken place between December 19 and 20. Meanwhile, the comet – or what was left of it – traveled almost due southward, being closest to Earth (0.50 AU) on January 7, 2012 and passing 1½ degrees from the south celestial pole two days later. While it traveled northward after that and became accessible from the northern hemisphere towards the end of January, there was little left to see; I successfully saw it a couple of times as nothing more than a ghostly "brightening" of the background sky. Observers with high-contrast cameras managed to follow it until mid-March.

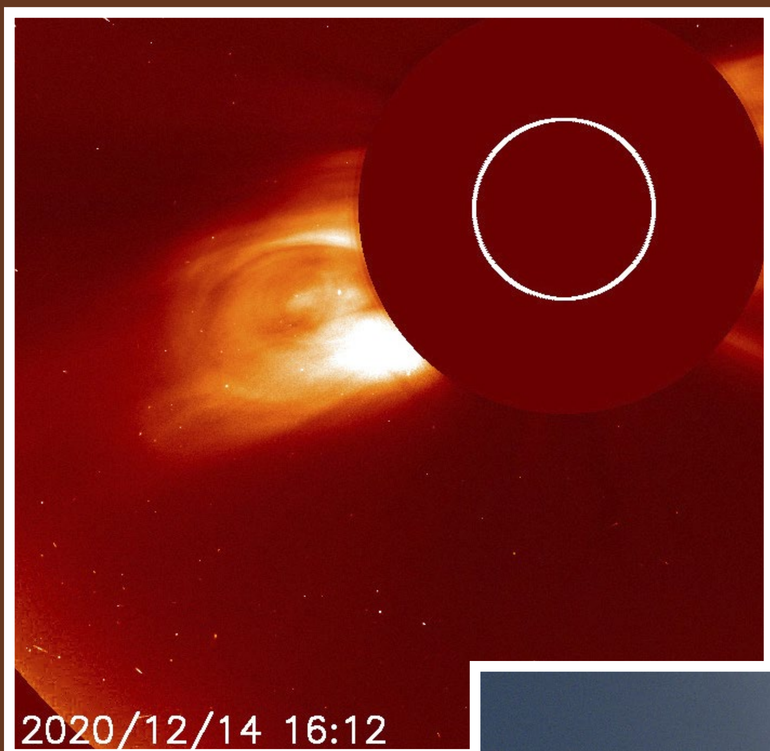
In the wake of Comet Lovejoy's appearance Sekanina and Chodas re-analyzed their earlier paper, and in so doing determined that the comet's orbital period is close to 700 years and that it indeed is the first member of the "cluster" they had predicted. We thus await future members of this "cluster" . . . There was some hope that a Kreutz sungrazer discovered in images taken with the Solar Wind ANisotropies (SWAN) ultraviolet telescope aboard SOHO in March 2012 might be such an object, since none of the other SOHO sungrazers – not even Comet Lovejoy – had been visible in SWAN images, however even though it was fairly bright when it appeared in the LASCO coronagraph images it was not abnormally so, and it disintegrated as it approached perihelion just like all the other SOHO-discovered sungrazers have done.

As we wait for future members of the Sekanina-Chodas "cluster" of Kreutz sungrazers to arrive, I hope we don't have to wait too long. Furthermore, especially since Comet Lovejoy was a "Great Comet" for observers in the southern hemisphere but was completely inaccessible from the northern hemisphere for almost the entire time of its passage through the inner solar system, I hope that at least one of these future sungrazers will pass through perihelion at a time of the year – ideally, in the September/October timeframe – that will allow those of us who reside north of the Equator to enjoy the show put on by one of these magnificent objects.

ADDED "IN PRESS":

While it certainly isn't a member of the incoming Sekanina-Chodas "cluster," a small Kreutz sungrazer (designated C/2020 X3) was photographed during the total solar eclipse this past December 14. It had been discovered the day before the eclipse (December 13) in images taken with the LASCO C3 coronagraph aboard SOHO by researcher Worachate Boonplod in Thailand, and during totality was roughly 6½ hours away from perihelion and visible in C2 images located approximately three degrees southeast of the sun. A German astronomer, Andreas Moeller, successfully imaged the comet from Neuquen, Argentina.

This is the second time that a SOHO Kreutz sungrazer has been successfully imaged during a total solar eclipse; as discussed in the "Special Topics" presentation on "Solar Eclipse Comets," Comet C/2008 O1 was imaged during the eclipse on August 1 of that year. I remain hopeful that I will be successful in both imaging and visually observing a Kreutz sungrazer during the eclipse on April 8, 2024.



Comet SOHO C/2020 X3 at the time of totality during the total solar eclipse on December 14, 2020. Above: The southeastern quadrant of the LASCO C2 image at the approximate time of totality from Argentina. The comet is above the slash between the "12" and the "14," and a short thin tail can be seen extending to the lower left. Courtesy NASA/ESA. Right: Image taken by Andreas Moeller from Neuquen, Argentina. This is cropped from the original image, and I have rotated it 180 degrees to match the orientation in the LASCO image. Courtesy Andreas Moeller (Arbeitskreis Meteore e.V.).

SPECIAL TOPIC: FORMATION OF THE PLANETS

Artist's conception of planetesimals within the planet-forming disk of the early solar system. Courtesy William Hartmann, Planetary Science Institute.

Ever since humankind began to discern the overall structure of the solar system a few centuries ago, i.e., that the sun basically resides in the center and the planets orbit around it, this has brought forth questions, for example, how did the planets, and the solar system as a whole, form? A second question would be, are there other planetary systems in the galaxy, and if so, how common are they? To a pretty large extent, the answer to the second question depends upon the answer to the first, in that if the processes by which the planets in our solar system formed are those that would not be expected to happen very often, then planetary systems would accordingly be quite rare. If, on the other hand, these processes are commonplace, then so should planetary systems be common.

A theory in vogue during the early 20th Century proposed that the planets formed by a collision, or near-collision, between the sun and another star; the encounter pulled material out of the interior of the sun (and presumably the other star as well), and this material cooled down to form the planets. Since the distances between stars are such that collisions, or at the least very close encounters, between them would be expected to be very rare, then there are likely very few planetary systems; indeed, our sun and the other star involved might have the only ones. There were numerous issues with this idea, not the least of which is the unlikelihood that the hot material pulled out from the sun could cool down into planets rather than dissipate, and it fell out of favor within a few decades.

Another idea had been proposed in the mid-18th Century by the German philosopher Immanuel Kant, and then independently, and in greater detail, in the 1790s by the French scientist Pierre-Simon Laplace. In this "nebular hypothesis," the sun was surrounded by

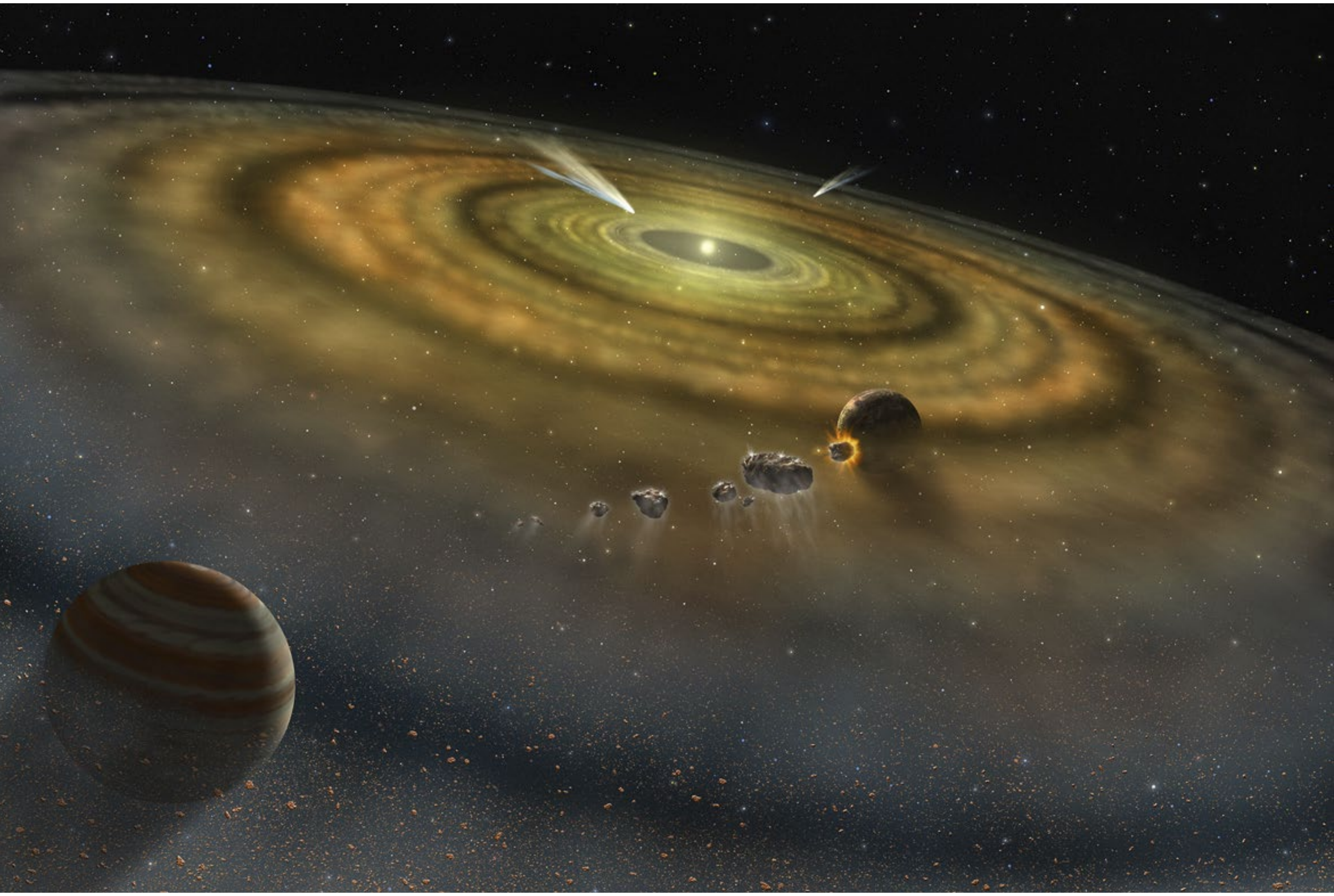
The star T Tauri (to upper right of center), with light reflected from surrounding dust clouds. Courtesy Adam Block/Mount Lemmon Sky Center/University of Arizona, licensed via Creative Commons.

an extended outer atmosphere, which due to rotation ended up being flattened into a surrounding disk. Over time the gaseous material in this disk cooled and solidified into the planets we see today. If this idea is correct then we might expect planetary systems to be rather commonplace, and during the late 19th and early 20th Centuries the "spiral nebulae" observed in telescopes were considered by some astronomers to be examples of this process. Today we know that these "spiral nebulae" are in fact external galaxies like our own, the spiral structures being composed of hot stars and gas.

There were nevertheless serious issues with this "nebular hypothesis," including the fact that there seemed to be no efficient way that the material within this disk could condense into planets. In 1969 the Russian astronomer Viktor Safronov proposed what could be called a variation of the "nebular hypothesis" that ended up addressing many of these issues; these ideas were later expanded upon by the American astronomer George Wetherill, and while many of the details remain to be worked out, today these ideas are accepted as being generally correct.

The overall general picture that we have today of the planetary system formation process begins with an interstellar cloud of dust and gas. The shock waves from a nearby supernova explosion triggered the formation of condensations within this cloud, which under their own self-gravity began to coalesce into stars. As these stars continued collapsing their rotation rate began to increase, and this faster rotation caused a non-trivial amount of the material to fall into a surrounding disk instead of onto the star. Over time the dust in this disk began to stick together and accumulate, attracting still more dust and material until objects a few km in diameter, called "planetesimals," were formed. In regions closer to the forming central star these planetesimals were primarily made of silicates and other "hard" material, whereas in the cooler regions far from the star the planetesimals were able to accumulate the gaseous, more "volatile" material as well.

Over timescales of tens to hundreds of millions of years, these planetesimals often collided with each other, and while the results of many of these collisions would involve the fragmenting of the planetesimals, some of these occurred at low enough relative



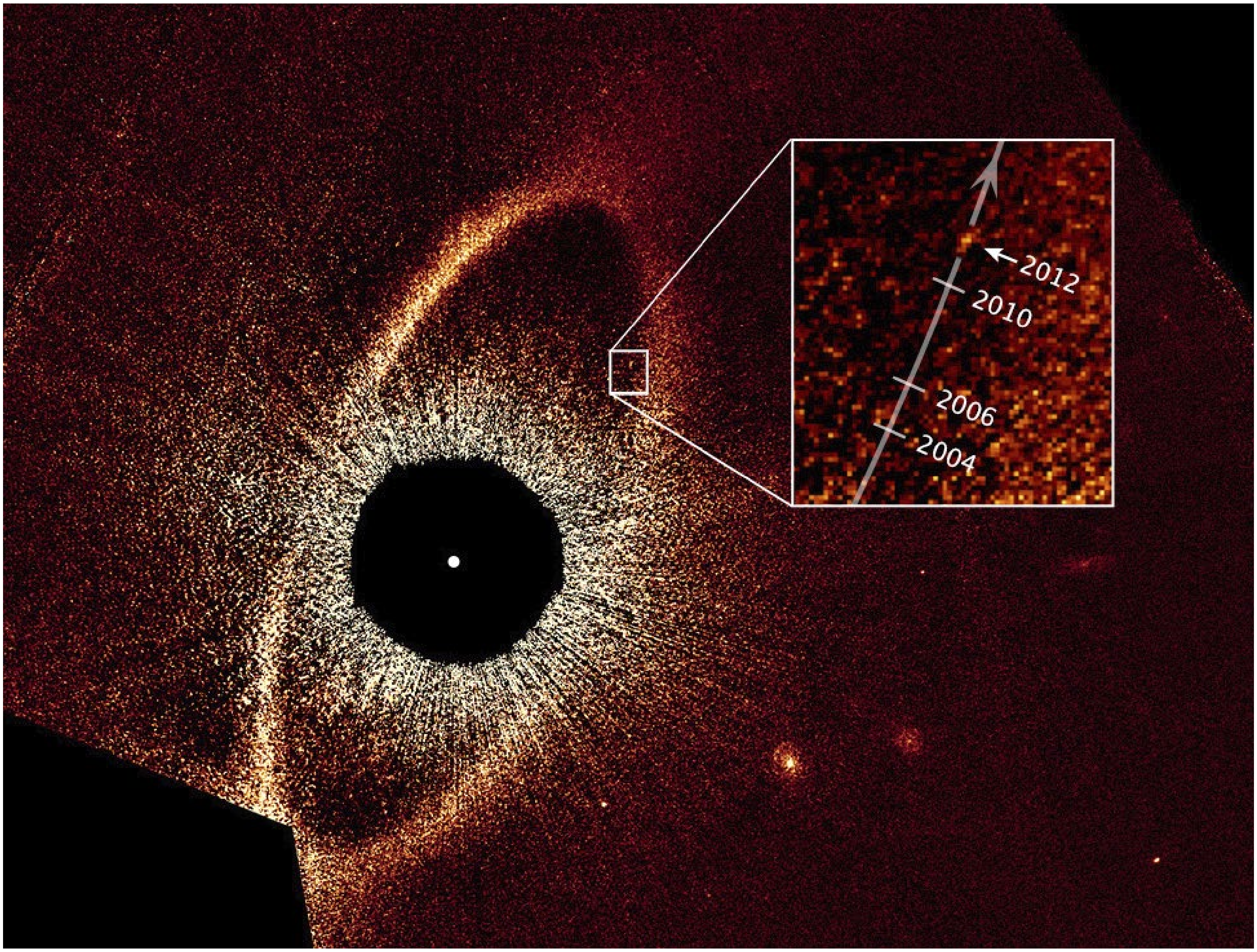
Current artist's conception of the planet-forming disk around Beta Pictoris, with rings of material, planets, and comets. Courtesy NASA/FUSE/Lynette Cook.

velocities such that they stuck together, creating larger objects that, due to an increased gravitational attraction brought about by a greater mass, were able to collect still more planetesimals. Eventually, larger objects, called "protoplanets," were formed, and the process continued, until eventually the large objects we today call "planets" resulted.

If such an idea is correct then we would expect to see evidence of such disks around other stars, especially younger ones where the planet-forming process is still going on. One of the earliest indications of such a disk came with the detection by University of California astronomer Martin Cohen in 1975 of the likely strong presence of water ice surrounding the young solar-type star HL Tauri. The presence of a gas disk was firmly detected at radio wavelengths by Annelia Sargent and Steve Beckwith in the mid-1980s, and has recently been imaged directly by the Atacama Large Millimeter/submillimeter Array (ALMA) telescope in Chile.

In 1983 the InfraRed Astronomical Satellite (IRAS) spacecraft detected excess infrared radiation, indicative of surrounding disks of dust, around several stars, including the bright naked-eye stars Vega and Fomalhaut. A year later, in December 1984 astronomers Brad Smith and Richard Terrile, utilizing telescope data taken from the Las Campanas Observatory in Chile, reported the first optical detection of such a disk, around the 4th-magnitude star Beta Pictoris. This particular star is of spectral class A6 and is approximately 1.75 times as massive as our sun; it is located 63 light-years away and is relatively young as stars go, being 20 to 26 million years old. The disk that Smith and Terrile detected extends over 1000 AU from the star and is presented nearly edge-on to our line of sight.

Numerous other such disks have been detected since then. The Hubble Space Telescope has detected several of these "proto-planetary disks," including around stars located within the Orion Nebula M42. Numerous very young solar-like stars, called "T Tauri stars" after the prototype (and which exhibit irregular



Hubble Space Telescope image of the disk around Fomalhaut (with the star itself blocked out via coronagraph) and its putative distant planet, taken January 8, 2013. Courtesy NASA.

flares of brightness, hence their classification as variable stars), exhibit spectral and/or other evidence for the presence of such disks; some of the older T Tauri stars do not show such evidence, suggesting that the planet formation process has essentially been completed around these objects.

The disk around Beta Pictoris has been especially well studied ever since the announcement of its discovery in 1984. It exhibits rotation as well as a distinct amount of structure including various sub-regions, rings of material, and a slight warping at its edges. At least one planet has been found orbiting within the disk, being perhaps seven times as massive as Jupiter and orbiting at a distance of 9 AU. The existence of a possible second planet, of similar mass but closer to the star, was announced in 2019 and confirmed just a few months ago, and meanwhile evidence for possible "exocomets" was reported in the mid-1980s and the existence of these was confirmed in early 2019, as discussed in a previous "Special Topics" presentation.

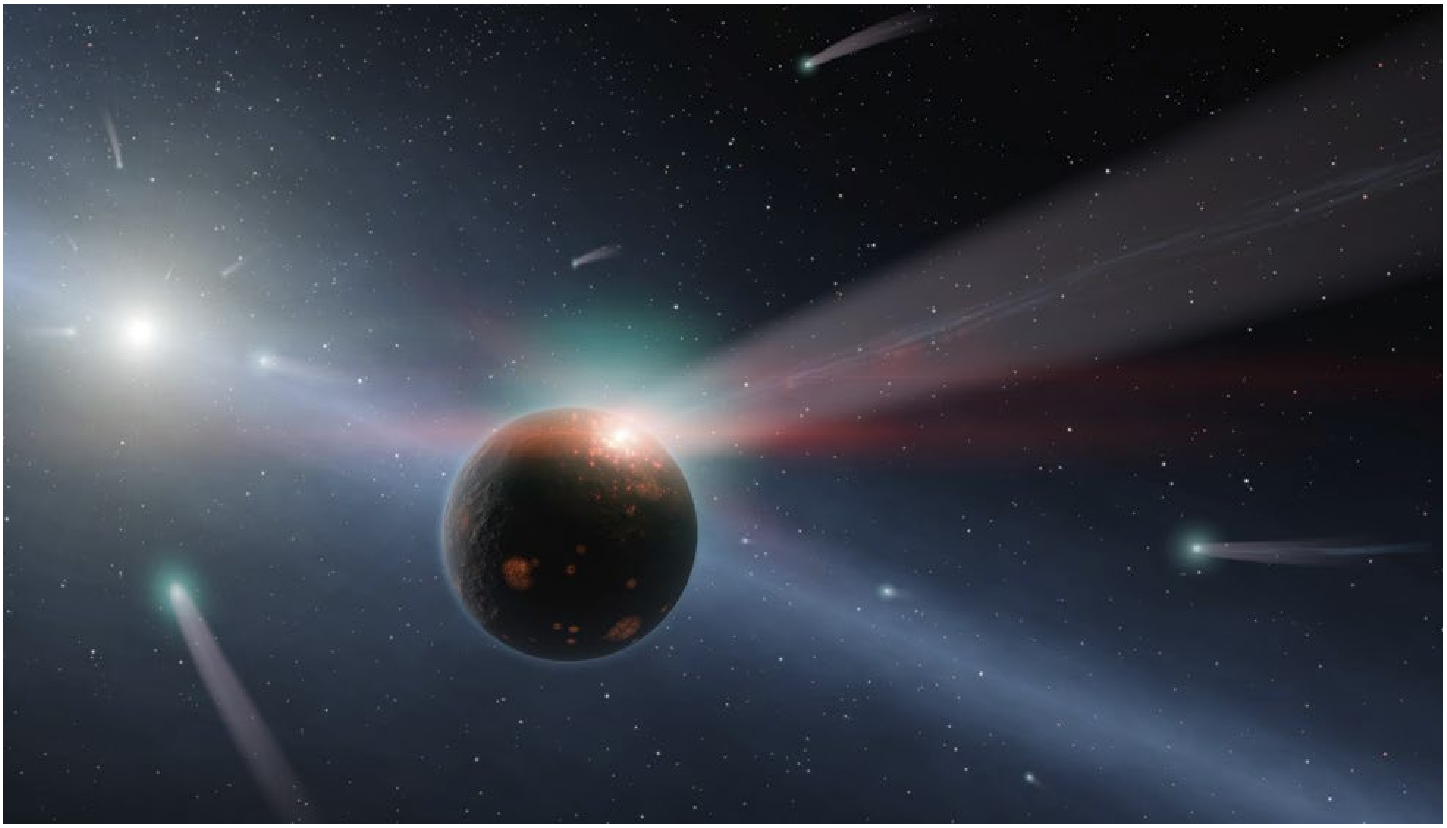
Similar forms of evidence have now been detected in and around the disks surrounding various other stars, as well as planets in some cases. A distant planet orbiting within the disk surrounding the bright star Fomalhaut was reported twelve years ago, although whether or not this object is an actual "planet" has recently been questioned; meanwhile, a handful of planets have been detected orbiting around T Tauri stars. Overall, at this writing over 4350 planets have now been confirmed orbiting around other stars, with over 700 multiple-planet systems having now been found. The evidence is overwhelming that planetary systems are indeed very commonplace in the Galaxy – indeed, it would appear that many, if not most or even almost all, stars have accompanying planets – and that the basic processes by which the planets in our solar system formed operate throughout the Galaxy as well. While the planets we have discovered thus far rather strongly suggest that our solar system is not a typical planetary system – and in fact there appears to be no such thing as a "typical" planetary system –

Artist's conception of the impact between Theia and the early Earth. Courtesy NASA/JPL-CalTech.

the basic underlying processes are still there.

These processes are not necessarily clean and orderly, however. Indeed, it is quite clear that the early solar system was a rather violent place, since there were many more planetesimals and protoplanets around then than there are today. The current model for the formation of the moon involves a Mars-size protoplanet – that has been given the name Theia – that was likely orbiting near one of the Earth-sun L4 or L5 Lagrangian points (discussed in a previous "Special Topics" presentation) that eventually was perturbed away from that spot into a collision path with Earth over four billion years ago. The moon subsequently would have coalesced out of the combined debris from Earth and from Theia. (Although versions of this model had been around for some time, it started to become the favorite in the late 1980s as a means of explaining the orbital and rotational configuration within the Earth-moon system as well as the internal geological structure of the moon and the composition of moon rocks returned by the Apollo missions.)

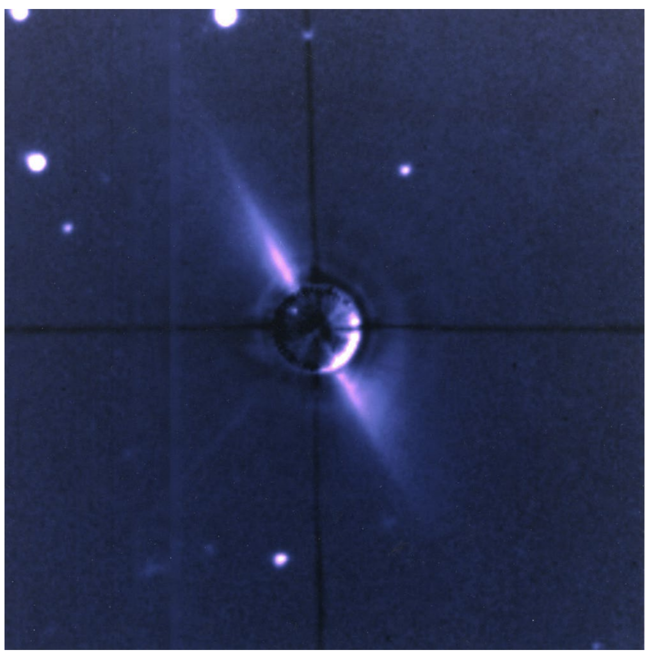
Although the consensus about this is not universal, there is relatively strong evidence that a period of "Late Heavy Bombardment" occurred in the inner solar system between 4.1 and 3.8 billion years ago. As mentioned previously, the population of planetesimals in the inner solar system during that era was significantly larger than it is today, and it is evident that the moon sustained many of the large impacts that produced the "maria" we see today during that time. The geological consequences for Earth during



Artist's conception of a "Late Heavy Bombardment" scenario taking place within the Eta Corvi system, similar to what is believed to have happened in our solar system four billion years ago. Courtesy NASA/JPL-CalTech.

this time would have been significant, and since life was getting started on Earth during that same time frame the biological consequences may have been even more profound.

To some extent, things seem to be much more quieter now, although "quieter" is perhaps a relative term. The discovery of the "hot Jupiter" planets – large massive planets orbiting very closely to their respective parent stars – back in the mid- to late 1990s introduced the idea of "migration" to our models of the formation and evolution of planetary systems, and it is quite clear now that the planets, including – especially – the large ones like Jupiter and Saturn, have migrated their orbital distances over the lifetime of the solar system. Over very long timescales, i.e., hundreds of millions to billions of years, none of the orbital configurations are stable, and the planets will undergo migration in the distant future. The effects on the other objects in the solar system, including Earth, would be enormous; for example, in one set of scenarios, Mercury could be perturbed out of its present orbit and undergo a close encounter with Venus, after which several possibilities could ensue, including an impact by Mercury into Earth.



An early image of the planet-forming disk around Beta Pictoris, obtained from Las Campanas Observatory in Chile by Brad Smith and Richard Terrile. The star itself has been blocked out via a coronagraph. Courtesy NASA/JPL/Richard Terrile.

While all this is going on, the sun will be undergoing its own evolution, eventually to reach the "red giant" phase some five to seven billion years from now, and it is far more likely that Earth will become uninhabitable due to changes in the sun than that it will become uninhabitable as a result of an impact by Mercury. For now, our solar system remains the relatively quiet place that we see it as being today . . . but nothing lasts forever.

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