SIRIUS ASTRONOMER

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The Newsletter of the Orange County Astronomers

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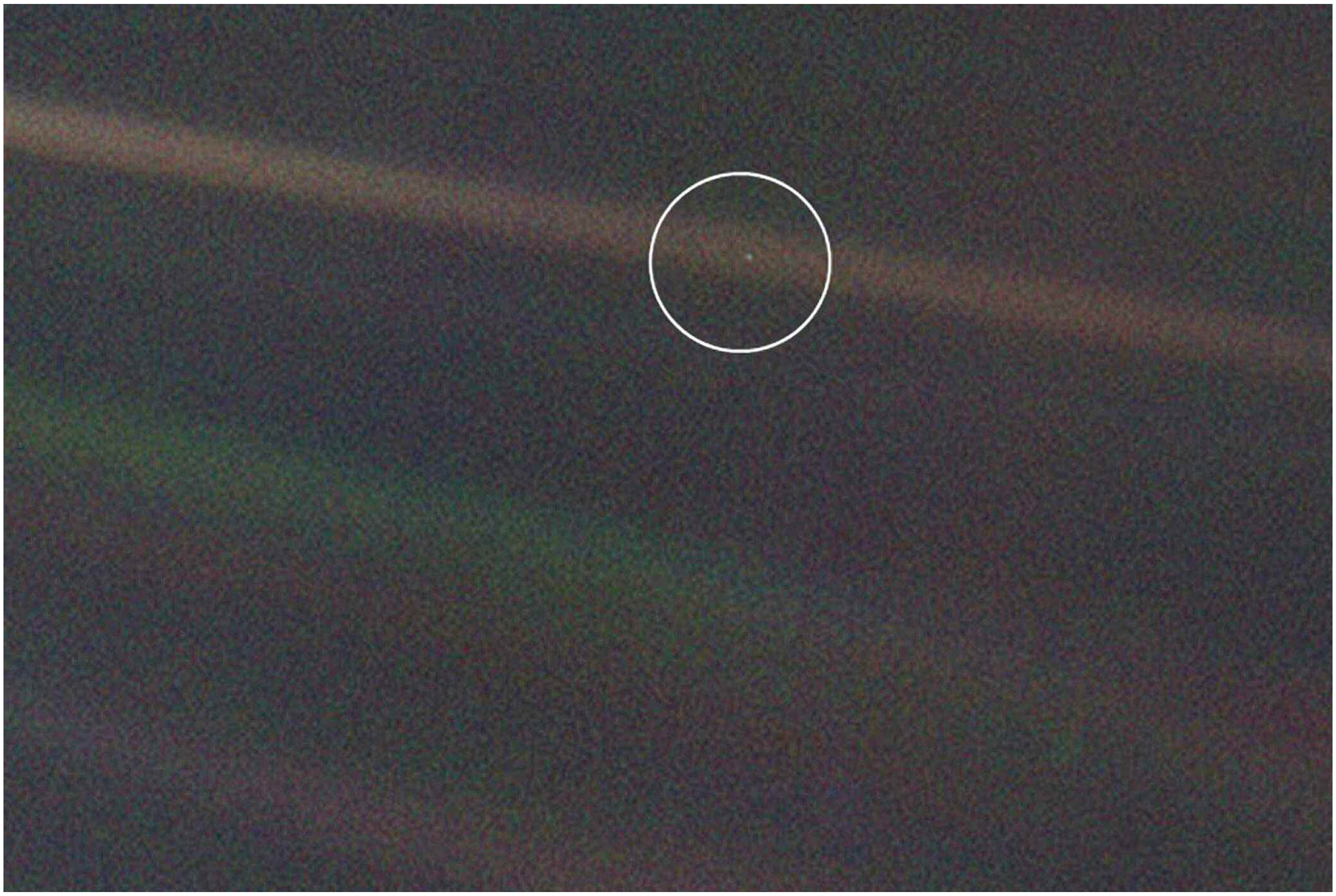


On February 14, 1990, at a distance of about 4 billion miles, Voyager 1 turned its 1500 mm high-resolution narrow-angle camera toward crescent Earth to take one last photo of our planet. Three separate frames were taken using blue, green and violet filters, with exposure times of 0.72, 0.48 and 0.72 seconds respectively. The frames were later recombined to produce this famously significant and humbling Pale Blue Dot image.

OCA CLUB MEETING

The free and open club meeting will be held on August 11 at 7:30 PM in the Irvine Lecture Hall of the Hashinger Science Center at Chapman University in Orange.

This month, Albert DiCanzio will speak about applications of Galilean experimental design to knowledge-discovery using the North American solar eclipses 2017 and 2024.

NEXT MEETINGS: September 8, October 13 (speakers TBA)

STAR PARTIES

Both the Black Star Canyon and Anza sites will be open on August 19. Members are encouraged to check the website calendar for the latest updates on star parties and other events.

Please check the website calendar for the outreach events this month! Volunteers are always welcome!

You are also reminded to check the web site frequently for updates to the calendar of events and other club news.

COMING UP

The next sessions of the Beginners Class will be held at the Heritage Museum of Orange County at 3101 West Harvard Street in Santa Ana on August 4 and September 1.

Youth SIG: contact Doug Millar

Astro-Imagers SIG:
Aug 8 (at **temporary location**: The Village at 17th Street) and Sept 12 (back in usual location)

Astrophysics SIG: Aug 18, Sept 15
Dark Sky Group: contact Barbara Toy

President's Message

By Barbara Toy

Well, we've finally arrived at the month that many of us in the astronomical world have been eagerly anticipating and planning for over the last year or more – in many cases, much more than the last year! The August 21, 2017 total solar eclipse that will be crossing the continental United States is finally here! To those who are planning to travel to the eclipse path to see it – I hope the weather and viewing are great for you, and that the roads where you are don't get too horribly congested!

For those who won't be in the path of totality – I hope you enjoy seeing the partial eclipse, which should be well worth seeing and pointing out to anyone around you who may be oblivious to this great celestial event. As Doug Millar mentioned at the July General Meeting, as one way to view it, you can make your own pinhole camera by making a small hole (literally using a pin to make the hole works pretty well) in a piece of paper or thin cardboard and letting the sun shine through it – it'll project an image of the sun that, during the eclipse, shows the moon crossing it so there's just a crescent of the sun still visible. I still remember one time many years ago when I'd forgotten that there would be a partial eclipse and I was walking under a row of trees shading the sidewalk. I realized that the shadows looked strange – closer examination showed that there were hundreds of crescent suns projected onto the sidewalk, some overlaying each other, caused by the light from the partially eclipsed sun coming through the leaves of the trees that were essentially forming hundreds of natural "pinhole cameras." That was definitely a fun view of the sun!

Wherever you are, however you view it, I hope you enjoy our great solar eclipse on August 21! And I look forward to hearing about all the different experiences our members have on that day!

Fifty Years of OCA:

Some of you may have noticed the slogan at the bottom of our website home page, "Bringing the universe into focus since 1967." Someone brought that to my attention recently, with the comment that this makes 2017 our 50th year as a club. We were actually formally incorporated in 1972, and I'm not sure exactly what event in 1967 was considered to be the starting point for the club – probably a meeting, but exactly when during that year it occurred or where or who organized it I'm afraid I don't know. From our membership list, it seems that Tim Hogle, who is still an active club member, is probably our last charter member, but we do still have quite a few members who joined in the 1970s and 1980s – it's pretty amazing that we have so many members who have been in the club for well over 30 years!

I'm sorry to say we overlooked this landmark when we had the banquet at the beginning of the year, as it would have been nice to commemorate it, but everyone who went to the banquet had a good time regardless and Joel Harris's talk on the upcoming eclipse was excellent and timely, so maybe we'll just consider that a commemorative event retrospectively. Having a major and reasonably local total solar eclipse in our 50th year is a pretty good way to make the year memorable, at any rate, even if we can't claim any role in arranging it...

From what I've been told by folks who were around in that period, there was an earlier attempt to organize an astronomy club in Orange County that certainly showed that there was a lot of interest in amateur astronomy here in the 1960s. Jim Leonard, who was subsequently an OCA member and is now deceased, was involved in that effort, and sent me an account several years ago of their first meeting, which was in his apartment – they had an overflow crowd show up, and there were so many cars that the street was totally blocked, so he got into a lot of trouble with his landlady. That earlier organization (the "OCAA") reportedly petered out when Jim and his fellow organizer got tired of doing all of the work to keep it going, and I don't know how many of the people who were involved with it ultimately wound up in our current club once it got going.

We began our formal life as the Orange County Amateur Astronomers Association, per our Articles of Incorporation in 1972, but that was amended in 1974 to Orange County Astronomers, the name we have used ever since. I believe that early general club meetings were held at the Santa Ana Library, and probably other venues, and I'm not sure when we first were able to meet in our current location at Chapman University, but that venue was well established when I joined in early 2000. We are very grateful to Chapman University for allowing us to use this facility for over 20 years now, and I hope our relationship with the University will continue long into the future!

When I joined the club, I was amazed at all that the earlier generations of club members had accomplished – at that point, we had the Anza site (which had been paid off years before), the club observatory with the Kuhn Telescope and Anza House were both finished and in active use, and all of the infrastructure at Anza was in place. That includes the well with the storage tank at the top of the property, water distribution lines and septic tanks for both the club observatory and Anza House, and our electrical system, which provides power to all of the pad levels and member observatories as well as the club observatory and Anza House. The only significant addition to our infrastructure since then has been on-site Internet access. As of 2000, all of the current member pad areas were installed, along with the general use pads in the Football Field below Anza House, and several of the observatories on the main member observatory level were in; since then, we have added a number of member observatories and a new member observatory level, but the interest in member pads has been met without adding any new pad areas.

Beyond the Anza site, we had our in-county observing area, which was at Silverado Canyon by arrangement with the Irvine Company when I joined but was moved to Black Star Canyon when the Irvine Company transferred a lot of its undeveloped land in the Santa Ana Mountains to the Nature Conservancy. Having an in-county area where we could have star parties under reasonably dark skies has been a great benefit to the club, as there are a lot of members who find it too difficult to make it out to Anza (which is at least a two hour trip from most areas in Orange County). Steve Mizera, our current Black Star Canyon Coordinator, advises me that the number of people who are regularly coming to these star parties is beyond the capacity of that viewing area, so he is looking at some alternative sites that the Irvine Conservancy (which now administers the area for Orange County Parks, the current owner of the area) has available, so our in-county star parties may be moving permanently to a new location in the Santa Ana Mountains with more room.

As of 2000, we also had a very active Outreach Program, thanks to the efforts of Jim Benet and the contacts he developed with many of the schools in the county. That program continued to grow and is now in the capable hands of our new Outreach Coordinator, Andy David, though Jim still helps out. As an aside, when we talk about doing Outreach, we tend to focus on the impact on the many people who get their first views through a telescope through these events and how satisfying that is to the volunteers who are providing these viewing opportunities, but another major benefit for the volunteers is getting to know the other club members who are involved in these events and learning from them – objects to view, equipment tips, information on club events, all kinds of things. For me, particularly in my early years in the club, doing Outreach events really gave me incentive (and resources in the form of knowledgeable fellow members) to learn more about the night sky, introduced me to many fellow members who became good friends, and also encouraged me to try different activities within the club that I might never have tried otherwise. If you haven't tried going out for any Outreach events yet, I really recommend it!

The club's Beginners Astronomy Class is another form of public outreach that was well-established when I joined in 2000. It's gone through some changes over the years but its fundamental purpose has remained the same, to provide a good basic astronomy class that is open to the general public as well as members. One major addition to its curriculum for at least the last ten years has been the "Bring Your Telescope" session, where our volunteers help people learn to set up their telescopes and help trouble-shoot those that aren't working. Another regular addition to the class has been the Beginners Astroimaging session, usually taught by Kyle Coker. Dave Pearson, who is currently responsible for the Beginners Class and is the instructor for the other four sessions in each six month cycle of the class, has streamlined and reorganized the material to fit these sessions in and to focus more on the information most relevant to the people who attend. As with most aspects of the club, this is a work in progress that evolves to meet changing conditions over time.

This overview wouldn't be complete without mentioning the club's Special Interest Groups. These have changed over the years, as well. In earlier days of the club, I understand there was an Astrophotography group (using film) and that those that were interested in using CCDs when those were becoming available were in the EOA, which I believe stood for "Electronics Oriented Astronomers." By the early 2000s, the imaging aspects of the two groups converged, and developed into what is now our AstroImaging SIG. Back in those earlier days, our club regularly organized astrophotography (later astroimaging) conferences (I've been told that we would alternate conferences with the Ventura club, which also has a long-standing interest in imaging); our last AstroImaging Conference was in 2006, which was quite a success but by then the annual Advanced Imaging Conferences were becoming established, RTMC was including imaging among its regular program topics, there were imaging sessions offered by Oceanside Photo and Telescope and other organizations, and those of us who were involved in organizing the OCA imaging conferences decided they were no longer really needed and there wasn't anything we could offer the general imaging community that other conferences weren't providing. Our current AstroImaging SIG remains a strong group, and we are fortunate as a club to have a large group of very capable imagers.

Our other currently active SIG is the Astrophysics SIG, which gathers to view videos on various aspects of astrophysics and to discuss them and other topics as the best kind of seminar group – a great place to improve your understanding of the universe at cosmic and quantum levels without any tests. I'm not sure exactly when it started, but I believe it was going strong as of 2000 and still is. The current coordinator, Bob Sharshan, sends out information before the meetings on what videos are planned (as well as other lectures and events he finds out about that might be of interest), which is a nice addition, the people who attend regularly are a friendly as well as knowledgeable bunch, and – at least back when I was last able to attend these meetings regularly – many would bring cookies or other refreshments, so we would joke about it being the "Astrophysics and Culinary Society."

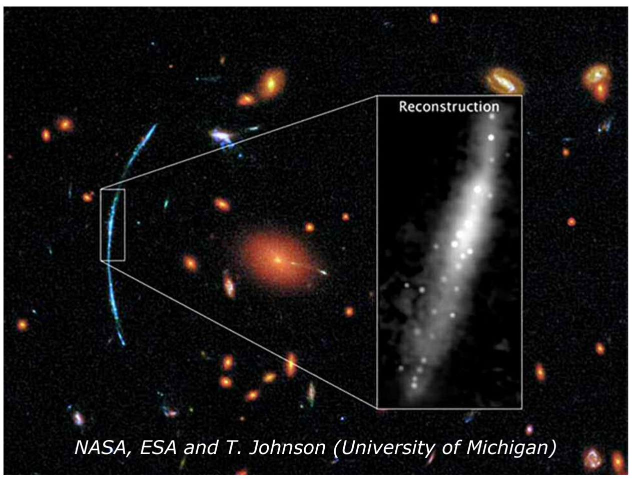
At the 50 year mark, we are a club with over 800 members engaged in a wide variety of astronomical activities. I'm sure there will be a lot of changes over the next 50 years, but I hope our successor members will still be enjoying the night sky and related activities, and still finding that amateur.

AstroSpace Update

August 2017
Gathered by Don Lynn from NASA and other sources

Galaxy orientation – Most galaxies are randomly oriented in space, but it has long been known that the largest galaxies often point toward their neighbors. A new study using the Hubble Space Telescope observations of very distant galaxies showed that this alignment of large galaxies has existed for at least 10 billion years. This means either that large galaxies formed already oriented along the cosmic web of matter, or that gravitational tugs of neighboring galaxies oriented the large galaxies relatively quickly after the Big Bang.

Red disk galaxy discovered – In millions of years after a galaxy stops making new stars, all the bright blue stars reach the ends of their lives, leaving only old redder stars. In the nearby Universe, the galaxies that have stopped making stars are all elliptical galaxies. A new image from the Hubble Space Telescope shows a very distant galaxy, so we are seeing it as it was billions of years ago, and it surprisingly has stopped making stars, so is redder, but it is a massive disk-shaped galaxy, not elliptical. Hubble was able to see the galaxy, though not very bright, because it is being brightened by a gravitational lens, formed by a foreground massive cluster of galaxies. The remote galaxy is 3 times the mass of our Milky Way galaxy, but only half the diameter. This will send the galaxy evolution theorists back to the drawing board.



NASA, ESA and T. Johnson (University of Michigan)

Early galaxy observed – Hubble was also used to observe a galaxy so distant that we are seeing it as it was 11 billion years ago, and it also is seen through a gravitational lens due to a foreground massive cluster of galaxies. The lens distorts the galaxy into a bright arc of light, a common effect of such lenses. Astronomers developed a computer program to reconstruct an image of the galaxy by undoing the lens's distortions. The result is an image that is much brighter and has 10 times better resolution than an image of a galaxy would at this great distance without lensing. About 2 dozen bright clumps of newborn stars are seen in the resulting image, each spanning 200-300 light-years. These are much smaller than theory had predicted for such clumps in the early Universe, so the theorists will have to revise.

Obscured black holes – A large fraction of all galaxies are thought to have their central black holes hidden from our view, at least at most wavelengths of light, presumably by a ring of matter orbiting the black hole. But there are 2 theories about the obscuring matter: it's an accretion disk relatively close to the black hole, or it's a much larger dust ring. New observations of the galaxy NGC 7582 using an imaging spectrograph (produces a spectrum of every pixel) showed that its obscuring ring is 2000 light-years across, whereas its accretion disk would be only about a couple of light-years across. The dusty obscuring ring also deflects the wind blowing out from the black hole so that much of the galaxy is protected from that wind. The observations also showed a cone-shaped outflow of gas being thrown out by the black hole. Previous radio observations of NGC 7582 show a small tail of neutral hydrogen, typically caused by a past encounter with a small galaxy. The observing team believes such an encounter could have formed the dusty obscuring ring. There are other theories to explain rings that obscure black holes, so further observations of galaxies with obscured black holes are needed to confirm this or one of the other theories.

Kepler catalog – The Kepler team released the final catalog of candidates for exoplanets found during the primary mission, where the spacecraft stared at a single field in Cygnus for 4 years. They are called candidates until other observations confirm they are planets, not some phenomenon that mimics planet transits, such as certain variable stars. This catalog contains 4034 candidates, of which 2335 have been confirmed. Of the candidates, about 50 are near the Earth's size and at the distance from their star such that temperature would keep water liquid (the so-called habitable zone). Kepler's follow-on mission, dubbed K2, changes its field of view every 80 days, and will produce many more exoplanet candidate catalogs in the future.

Rocky vs. gas planets – A new study using Kepler data and independent observations to determine star diameters has calculated improved planet diameters for a sample of planets roughly Earth-sized. The study found there is definitely a gap between planets a little larger than Earth and planets a little smaller than Neptune (which is about 4 times Earth's diameter). It is thought that this is the divide between rocky planets and gas giants. Apparently if a planet starts acquiring gas (mostly hydrogen) during its formation, it acquires a bunch of it and quickly transitions to a gas giant, leaving no fully formed planets in the newly discovered size gap.

Double star planets – A study was made of 50 stars with Kepler-discovered planets to determine how many of the stars were double stars. A second star could escape detection by Kepler if they were too close to resolve. The light of a second star would throw off a number of calculations: the diameter of the planet, the orbital distance, whether a planet is in the habitable zone, the density of the planet, and whether it is a rocky or gas giant planet. Of the 50 stars, the new study showed that calculations about the planets were substantially wrong in 5-15 cases due to ignoring the effects of a second star in the system.

Gas giant planet formation – A new study of massive exoplanets found that those under 4 Jupiter masses form in different environments than those over 4. The smaller ones form orbiting smaller metal-rich stars, and the larger planets orbit larger metal-poor stars. It is believed that these 2 classes represent 2 different methods of planet formation: the lower mass planets by core accretion, and the higher mass by gravitational instability.

Exoplanet imaged – A team of astronomers has imaged an exoplanet orbiting the star HIP 65426. Though thousands of exoplanets have been found by various techniques, taking an image of one is still quite rare. Planets are too dim and too close to their glaring stars in most cases. The diameter of the planet is about the same as Jupiter, but its mass is 6-12 times as great. It is also much hotter, at about 1900-2400°F (1000-1300°C). Observations match computer simulations of a dusty, cloudy atmosphere. The planet is 92 AU (where Earth is 1 AU from the Sun) from its star, 3 times the distance of any planet in our Solar System from our Sun. This great distance helped to make it imageable. This young planet unexpectedly does not have a debris disk, the stuff normally left over from planet formation. The planet's star has one of the fastest rotations, 12 times as fast as the Sun. It is possible that the fast rotation somehow caused the debris disk to dissipate. Theorists are having a hard time seeing how a large planet could form about a star spinning this fast. More investigation is needed. The team has observed about 300 young nearby stars, and this is the only planet they have managed to image. This implies that planets separated far enough from their stars to be imaged are rarer than predicted

Double free-floating planet – Observation using adaptive optics of one of the few known free-floating planets, that is, one not orbiting a star, showed that it is actually double. Each has the mass a few times that of Jupiter, so they are planets, not brown dwarfs (which are more massive). They are separated by about 4 AU. They are about 10 million years old, which was determined by the age of a nearby group of stars, with which the planets were found to be associated.

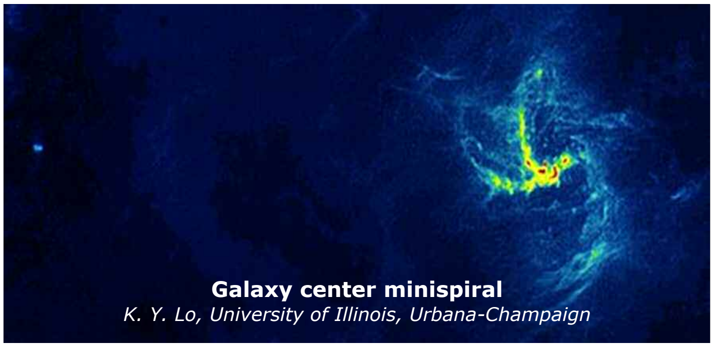
Nearby brown dwarf discovered – Backyard Worlds is a citizen-science project where volunteers examine images taken by the WISE infrared space telescope to find planets and other objects. A recent success was finding an object that further observations showed to be a nearby (100 light-years away) brown dwarf. A brown dwarf is a star that did not form with enough mass to sustain nuclear fusion, the energy source that powers ordinary stars. Though there should be billions of brown dwarfs in our Milky Way galaxy, only a few dozen are confirmed, and perhaps thousands suspected, not billions, because they are so dim.

Brown dwarfs numerous – New deep observations of a massive star cluster (RCW 38) found about ½ as many brown dwarfs as stars, supporting the belief that our galaxy must contain as many as 100 billion brown dwarfs. This agrees with previous deep images of smaller star clusters, which also found huge numbers of brown dwarfs. The new observation implies that brown dwarf formation occurs in the same manner regardless of the size of star-forming regions.

Smallest star discovered – A team of astronomers searching for exoplanets found a body whose mass was determined to be 85 times that of Jupiter. Theoretically, a body over 83 Jupiter masses can sustain nuclear fusion, and therefore this is a true star (not a brown dwarf or failed star). So this is the least massive star known. Its diameter was determined, and it is the smallest diameter star known that is still undergoing nuclear burning (neutron stars and white dwarfs, having exhausted their nuclear fuel, shrink to far smaller). Its size is between that of Jupiter and Saturn. It has been named EBLM J0555-57Ab, and is about 600 light-years away

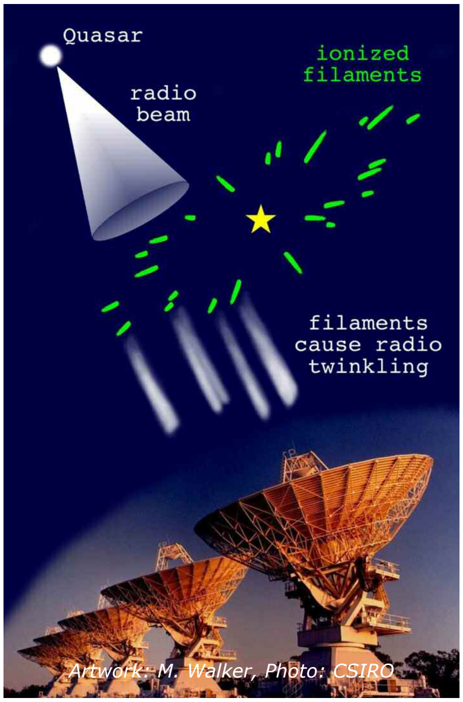
Hypervelocity stars found – The first release of data from the Gaia mission had the positions of a billion stars, but not their motions (which will come in later releases). But a catalog was released that compared star locations to Tycho (previous mission) locations and was able to yield motions for 2 million stars. So a team of astronomers wrote a computer program to sift through the 2 million stars to find hypervelocity stars, those which have far higher velocity (typically double or more) than stars in ordinary orbits about the Milky Way galaxy. The program was actually trained to find stars that share characteristics with the known hypervelocity stars. They found 6 new hypervelocity stars that were headed directly away from the galaxy center, and therefore were thrown out by interaction with the central black hole. Only about 20 of these were previously known. Only one of the new 6 has enough velocity to entirely escape the Milky Way. The program also found 5 new stars with hypervelocity, but not aimed away from the galactic center. These are thought to be the result of gravitational slingshot effects of multi-star encounters. The astronomers are anxious to run their program on a future full Gaia release with a billion stars.

ALMA – (radiotelescope array in Chile) was used to observe the center of our Milky Way galaxy. This showed in greater detail than before the "minispiral" of material there, which resembles a barred spiral galaxy, but is many thousands of times smaller. The temperatures, densities, and motions of the material in the minispiral were measured. The goal is to understand how this shape formed and what keeps it from dissipating.


Galaxy center minispiral
K. Y. Lo, University of Illinois, Urbana-Champaign

Unusual binary star discovered – A white dwarf star known as WD 1202-024 was discovered in 2006. Recent investigation into its variations in brightness showed that they were caused by a brown dwarf orbiting about it closely. They are separated by only 80% the distance that our Moon is away from Earth, and orbit once every 71 minutes. The white dwarf went through its end-of-life as an ordinary star about 50 million years ago, at which time it would have swelled up to a huge red giant before shrinking to a white dwarf. The amazing part is that as a red giant, it would have been so large as to engulf the brown dwarf, which apparently survived the ordeal. The pair are drawing closer to each other, so that the brown dwarf will start losing material gravitationally onto the white dwarf in 250 million years or so. They are about 2700 light-years away

Binary black hole – The VLBA radiotelescope array was used to observe a galaxy with 2 central black holes, and for the first time orbital motion of such a pair was detected. The galaxy, known as 0402+379, is about 750 million light-years away. The combined mass of the black holes is about 15 billion times the Sun's mass, and orbit each other at an estimated 24 light-years separation. They take roughly 30,000 years to complete each orbit. The galaxy likely acquired its second black hole by stealing it from another galaxy during a collision of galaxies.



Artwork: M. Walker, Photo: CSIRO

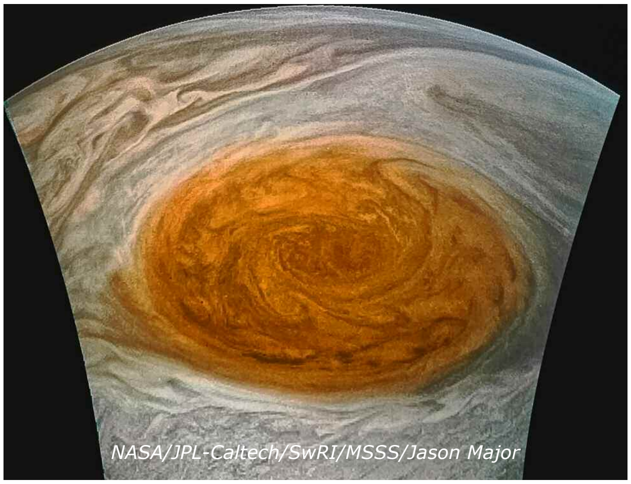
Wild twinkling quasars explained – Most quasars twinkle somewhat in radio light, but a few of them dim and brighten wildly over just a few hours. One wild quasar was noticed to be near the bright star Spica. Investigation of a few other wild quasars found they were also near hot stars. They are, of course, only apparently near, as stars in our galaxy are typically millions of times closer than quasars. Very detailed observations of 2 of these quasars showed that the hot stars are surrounded by long thin gas filaments radiating outward. Quasar radio light passing through these filaments is causing the wild twinkling.

Xenon – New results from the recently concluded Rosetta mission include an analysis of the isotopes of the gas xenon found on Comet 67P. This should help answer the long-standing dispute regarding where the Earth's oceans and atmosphere came from, as 1 of the 3 main theories is that comets striking the early Earth delivered them. Starting from measurements of Earth's current xenon isotopes, astronomers then projected back how much of each isotope has been lost over the life of Earth. The Rosetta results indicate that 22% of Earth's atmosphere was delivered by comets such as 67P, and the remainder probably from asteroids.

New Horizons (used Pluto spacecraft) – Astronomers predicted that the outer Solar System body (2014 MU69) toward which New Horizons is now heading for a January 2019 flyby, was to occult (pass in front of) a star in June. So they set up a row of telescopes across the path on Earth from which this could be observed. The occultation was not observed. Likely this means that the body's size is much smaller than estimated, and its shadow passed between 2 of the telescopes. From its known brightness, this small size would mean it is extremely reflective. Two more occultations during July will be observed. Also the airborne SOFIA telescope and the Hubble Space Telescope will be observing the body to see if there are any moons or rings or other debris near it, since such could harm New Horizons.

Planet Ten? – You have probably heard about Planet Nine – the planet predicted to exist far out in the Solar System, in order to explain the similarities in orbits of small bodies in that region. Now other astronomers are predicting another planet, much smaller (perhaps as small as Mars) and much closer (though still far beyond Neptune). It would explain the inclinations of another group of small bodies in the outer Solar System. Searches for both will proceed.

Juno in July flew over Jupiter's Great Red Spot at the closest distance ever (5600 mi = 9000 km) and obtained spectacular pictures of this huge storm (larger than the Earth).


NASA/JPL-Caltech/SwRI/MSSS/Jason Major

New spectroscopic and imaging observations of the exoplanet **51 Eridani b** have been found to best match computer simulations of a mildly warm gas giant planet with patchy clouds.

New observations with the Jansky Very Large Array radiotelescope in New Mexico show a protostar (forming star) in Orion that shot out a jet of material about 100,000 years ago, which struck a gas cloud and apparently caused it to condense into another (younger) protostar. This confirms certain **star formation** theories.

China launched its first astronomical observatory in space, a wide-field X-ray telescope with very broad wavelength capabilities and an accompanying gamma-ray telescope. The project was known as HMXT, and was after launch given the name **Huiyan** (means insight).

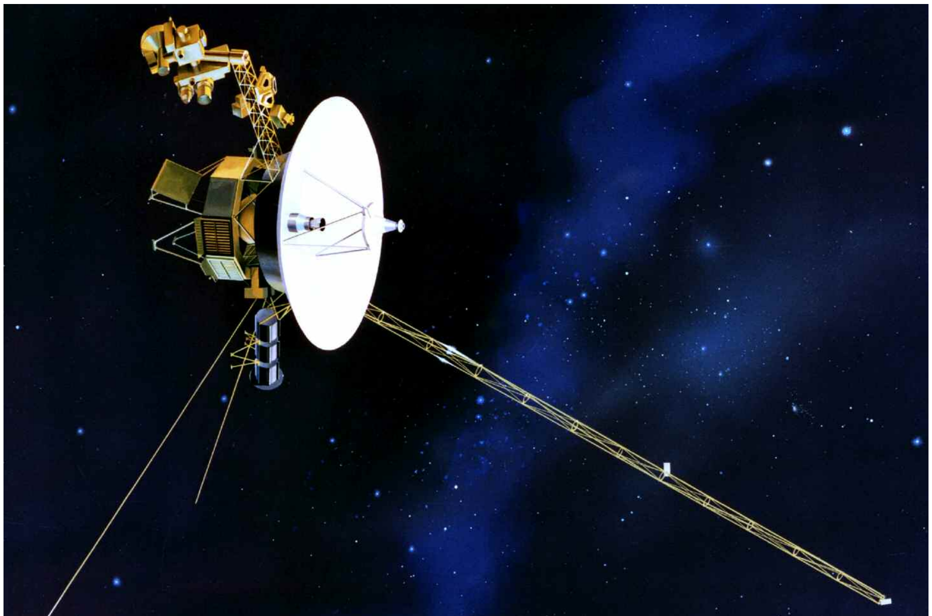
Mars rover **Curiosity** controllers have developed new software to control the wheel motors, that changes the forces applied to various of the 6 wheels when going over uneven terrain. The purpose is to reduce strain and damage to the wheels and prolong their lives.

A group of amateur astronomers set up a line of telescopes to observe the asteroid **Amalthea** (not to be confused with the moon of the same name) occult a star in March, and the results showed it has a very elongated shape and it has a moon.

Voyager Mission 40-Year Tribute

By Tim Hogle, OCA Charter Member

This year marks the 40th anniversary of the launch of NASA's Voyager 1 and 2 spacecraft to the outer planets. Although built and funded only for a first-ever, four-year mission to fly by Jupiter, Saturn, their moons and rings, Voyager 2 went on to obtain the only close up views of the Uranus and Neptune systems as well. Both spacecraft have subsequently continued to explore the outer regions of the heliosphere. Voyager 1 has crossed over the heliospheric boundary into interstellar space, and Voyager 2 is expected to do likewise in the next couple of years. Although the cameras were turned off many years ago, there still is a complement of instruments operating which are well-suited for measuring the magnetic fields, plasmas, cosmic rays and other particles in that environment; measurements that cannot be duplicated from Earth.



Rendering of the Voyager spacecraft. Image credit: NASA/JPL-Caltech

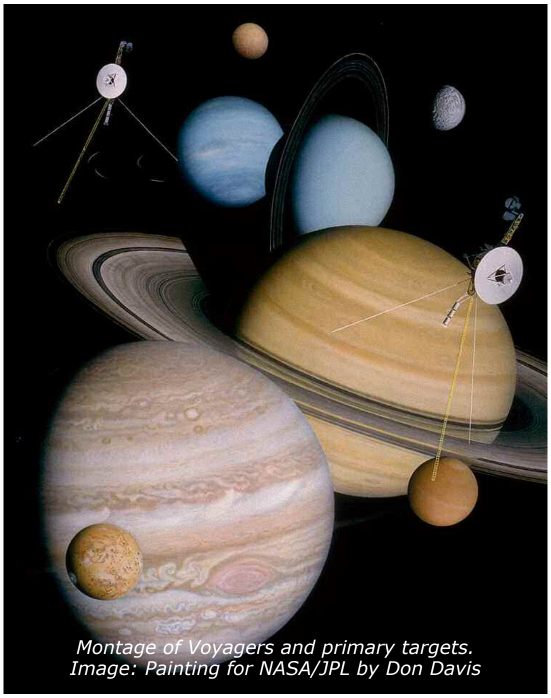
The Voyager mission arose out of what was originally termed the Outer Planets Grand Tour mission in the 1960s, in which a combination of three spacecraft was envisioned to fly by Jupiter, Saturn, Uranus, Neptune and Pluto (remember, the latter was a planet then). This was based on a recently-discovered, once-in-175-year opportunity that allowed using the (then completely theoretical) gravitational slingshot effect to get from one planet to the next in conjunction with a modest amount of hydrazine fuel on board for trajectory correction and attitude control.

But in an era when space missions were measured in weeks to months, building spacecraft with the necessary reliability to survive the 12 years required was unheard of, even at the Jet Propulsion Laboratory, unquestionably the world's most experienced and successful space mission organization. So, budget and development time constraints resulted in a compromise – a four-year mission to Jupiter and Saturn (about the limit anyone was willing to say was possible with the technology of the day) with two spacecraft, primarily to provide a back up in case one failed. The original Grand Tour designation was renamed to the more modest Mariner Jupiter Saturn 1977 (MJS-77), and work began in earnest following the successful first close up view of Jupiter by Pioneers 10 and 11 in 1970.

MJS benefited from the Pioneer experience in developing these next craft, in particular recognizing the need for much more radiation shielding than was originally expected – a good thing, as with the Voyagers' closer flybys to Jupiter (necessary to get the required slingshot effect) they would not have survived the Jovian radiation environment with less shielding than the amount added as a result of analyzing Pioneer's data. Shortly before launch in 1977, the project was renamed Voyager, in recognition of its very different nature than the previous Mariner missions, on which it had originally been modeled.

Although Voyager 2 was launched first (August 20, 1977), Voyager 1 followed it (September 5) on a faster trajectory that put it four months ahead of its twin in reaching Jupiter (1979) and nine months ahead at Saturn (1980 and 1981). The final plan was that if Voyager 1 was successful at both encounters (including a close flyby of Titan, which, being the only satellite in the solar system known at the time to have an atmosphere, was considered of equal scientific importance to Saturn itself), Voyager 2 would be redirected to a less optimum Titan flyby that would put it on course for Uranus (and Neptune). This decision was also to be predicated on analyses that showed the flight systems to be healthy enough to make the additional 5-year journey to Uranus. At the time, Neptune (3½ years further out than Uranus), was given little thought, because the concept of Voyager 2 surviving for a total of 12 years in space was still considered by almost everyone (but not by me) to be almost a pipe dream. Virtually no one gave thought to what might come after Neptune, except to recognize that the trajectory for both spacecraft would take them forever out of the solar system.

The Voyager 1 Saturn encounter was considered entirely successful, and it was believed that Voyager 2 could not gain any additional scientific value at Titan due to the dense haze and limited instrument capabilities (neither spacecraft could see the surface). With a good prognosis for Voyager 2 to last another 5 years, the go-ahead was given to modify its trajectory for the more distant flyby of Titan and on to Uranus. That day marked the most significant turning point of the entire mission.



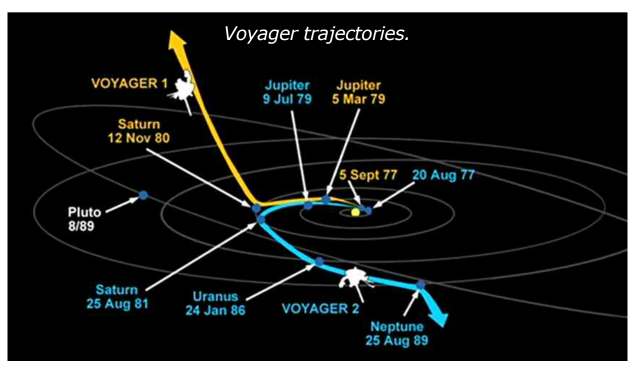
Montage of Voyagers and primary targets.
Image: Painting for NASA/JPL by Don Davis

In order to make the extended mission to Uranus and Neptune possible, some new and never-before-tried technologies had to be designed into the spacecraft and novel new techniques for using the hardware to its fullest had to be validated for use. One notable requirement was the need to improve error correction coding of the data stream over the very inefficient method which had been used for all previous missions (and for the Voyagers at Jupiter and Saturn), because the much lower maximum data rates from Uranus and Neptune (due to distance) would have greatly compromised the number of pictures and other data that could have been obtained. A then-new and highly efficient data coding method called Reed-Solomon (RS) coding was planned for Voyager at Uranus, and the coding device was integrated into the spacecraft design. The problem was that although RS coding is easy to do and the encoding device was relatively simple to make, decoding the data after receipt on the ground is so mathematically intensive that no computer on Earth was able to handle the decoding task at the time Voyager was designed – or even launched. The increase of data throughput using the RS coder was about a factor of three over the old, standard Golay coding, so including the capability was considered highly worthwhile. It was assumed that a decoder could be developed by the time Voyager needed it at Uranus. Such was the case, and today RS coding is routinely used in CD players and many other common household electronic devices.

Other spacecraft enhancements included developing a technique to pan the entire spacecraft to compensate for smearing of pictures that would have occurred with the long exposures needed for dim sunlight (think of a telescope clock drive to avoid blurring of an astrophoto, but only turned on for the duration of the exposure), and compression of imaging data using what was intended as a back up flight data computer (the extra processing power provided much faster on-board processing to further increase effective data throughput).

Also, during Voyager's 5-year journey to Uranus, new equipment and novel techniques had to be developed and implemented in the ground data systems. Multiple Deep Space Network (DSN) and large radio astronomy antennas across the globe were combined into arrays, ultra high sensitivity receivers were developed, and the biggest three DSN antennas were enlarged from 64- to 70 meter diameters. The total spacecraft and ground system enhancements increased the effective amount of data captured by more than a factor of ten compared to what would have been the case without the enhancements.

The success of the mission at all four planets is without parallel. Voyager was considered, hands down, the most successful space mission in history, and it still is by many measurements. Although the resolution of pictures at Jupiter and Saturn has been superseded by orbiting spacecraft since then, Voyager was the first to discover rings at Jupiter, volcanism outside the Earth (Io and Triton), the fine structure of Saturn's rings and the enigmatic spoke effect, as well as to see for the first time the intricate structure of the outer planets and satellites, along with discovery of the complex interplay of gravitational dynamics, and radiation and particle fields that make each planetary system so unique. In fact, probably the most striking discovery overall was the recognition that the outer solar system is, and always has been, a very dynamic and active place, far from the boringly cold, dead worlds envisioned before the Voyagers arrived.



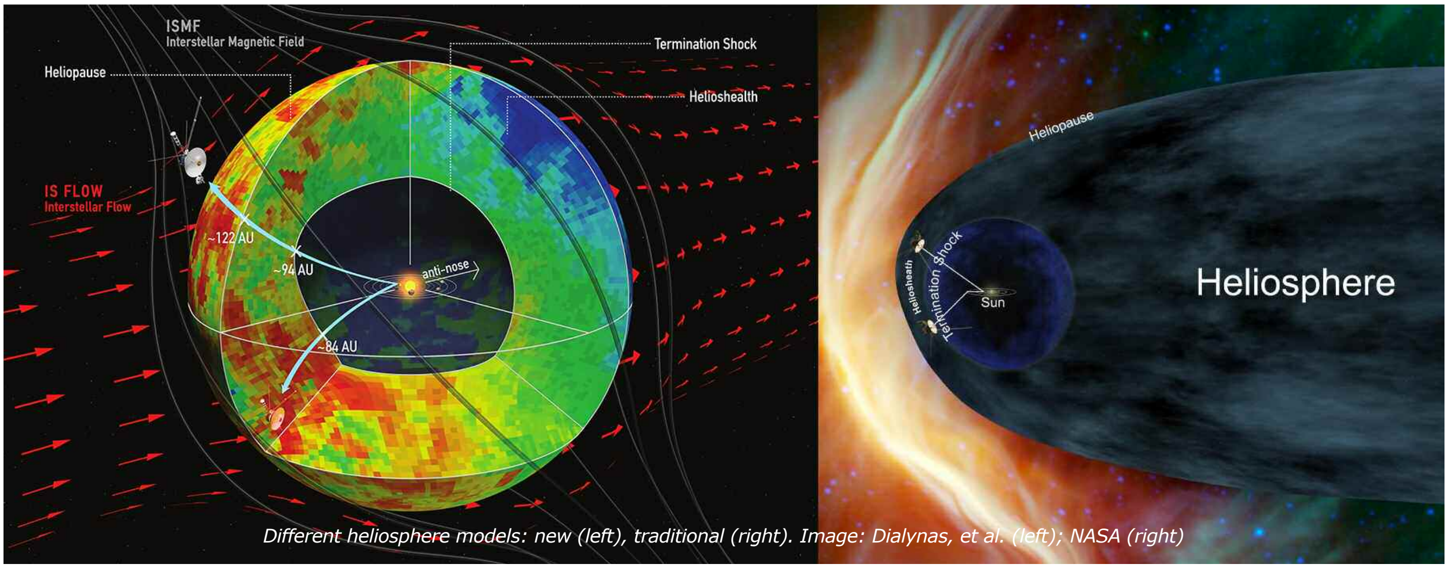
Voyager trajectories.

This success made for a delightful bonus. Both spacecraft were still healthy after Neptune in 1989, so plans were developed to use these still-robust craft for an extended mission. No more targets could be visited. Pluto would have required a 180 degree course reversal for Voyager 2 at Neptune (travelling 30,000 plus mph), and Voyager 1 was well above the ecliptic plane after its Saturn encounter, a necessary condition of the close Titan flyby. And even Voyager 2 was on a strong southerly route after Neptune due to the need to practically skim the cloud tops of Neptune's north pole in order to get a close look at Triton.

Both spacecraft had more than solar escape velocity because of the slingshots at their planetary flybys. This meant that the outer regions of the solar system could be fruitfully explored with the remaining fields and particles instruments. And there were two theoretical boundaries that might be characterized by the Voyagers: the termination shock, where the solar wind would suddenly go subsonic when its strength weakened to equal that of interstellar winds, and the heliopause, where the sun's magnetic field and solar wind influence would mix with that of interstellar fields and winds, and the latter would become dominant.

And so what is now termed the Voyager Interstellar Mission (VIM) was born. Its environment is a completely unexplored region, and the distances and uncertainties to the above theoretical boundaries were greater than any previous targets. So the extended mission had to be completely success-oriented and quite indefinite. Budget pressure from higher priority missions continually eroded the Voyager budget and made mission cancellation a constant threat until in 2004 Voyager 1 finally punched through the termination shock, validating the credibility of the extended mission. In 2007 Voyager 2 followed suit, and in 2012 Voyager 1 crossed the heliopause boundary and is now sampling the interstellar medium. Voyager 2 is expected to cross this boundary in the next couple of years. This revalidates Voyager's continuing achievement of "firsts" for mankind.

Voyager 1's crossing of the heliopause, along with ancillary data from the Cassini and IBEX probes, has resulted in an updated model of the shape of the heliosphere. While debate continues on which model is correct, the new one shows a much more spherical shape than the long, parabolic shape of the traditional model. The attached picture shows the alternate views.



Different heliosphere models: new (left), traditional (right). Image: Dialynas, et al. (left); NASA (right)

So what does the future hold for these intrepid explorers? The rather primitive computers on board using late 1960s technology and 4k, 16-bit memories for computer command and attitude control, and 8k for flight data computers, mean that the spacecraft still require a small, dedicated team of engineers to plan and send sequences of commands to augment automated sequences stored on board, monitor the data for anomalies, and be prepared to respond as appropriate. The time it takes to get a command to Voyager 1(2) is 19(16) hours at the current nearly 140(115) AU, and just as long to get a signal back. So NASA will need to provide funds for continued operation as long as the mission is deemed worthwhile.

And how long is that? There are three parameters which are identified as potentially mission-limiting. The first is data rate; the further the distance, the lower the rate that can be supported. The minimum science data rate transmitted by Voyager is 160 bits/second. With use of the high power transmitter mode on the spacecraft and arraying of DSN antennas, this should allow reception of data for at least 20 years, though improvements in ground data systems could extend that, and a lower spacecraft data rate could be used.

The second limit is hydrazine fuel for attitude control. But again, this is in good supply due to efforts throughout the mission to conserve fuel that have left nearly a quarter of the hydrazine loaded at launch still in the tanks. This could last for another half century if used carefully.

The real limiting resource has long been seen as electrical power. The output of the radioisotope thermoelectric generators is directly related to the decay of the plutonium fuel source, and can't be changed or stored. With an output of about 250W currently, it is expected that the minimum level to operate just the computers, transmitters, and receivers to keep data flowing and heaters to keep the hydrazine from freezing is about 200W, which will be reached quite predictably in 2025. At that point there will be insufficient power to keep even one science instrument operating. Practically speaking, this will define the end of the active mission, although some power sharing might be applied to extend this date by a few years.

Beyond this, the final extended mission begins. The Voyagers each have a gold plated video disk (1970s technology, of course) with images of Earth and its occupants, music and other sounds, greetings from world leaders, detailed instructions in what is thought to be universal scientific notation on how to play the record, and an Earth location map relative to nearby pulsars. Remote as the possibility may be, the thinking was that a sufficiently advanced civilization could conceivably capture one of these derelict spacecraft, figure out how to play the record and thereby gain some understanding of the civilization that launched it. But even at the current speed of roughly 1 million miles per day, Voyager 1 is not due to come closer to another star (Sirius) than the sun for 300,000 years, and 40,000 years (star AC+79 3888) for Voyager 2. Whether they are found or not, these time capsules exist as an introduction to us that may outlast human civilization.

Although we would like to think that humanity will continue to thrive, here or on a nearby planet or even around a nearby star, that next big asteroid with Earth's name on it, the upcoming ice age, or a runaway global warming (or cooling) could wipe us out. And eventually, as the sun enters its red giant phase in four billion years or so, Earth will be burnt to a cinder, eradicating all evidence of our existence here. Irrespective of our own futures, the Voyagers should continue to carry our message into the cosmos, relatively unimpeded for far longer than what might be our own limited time horizon.

Tim Hogle was a spacecraft systems engineer on the Voyager Flight Team from 1978-2006.

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Twenty Years Ago on Mars…
By Linda Hermans-Killiam

On July 4, 1997, NASA's Mars Pathfinder landed on the surface of Mars. It landed in an ancient flood plain that is now dry and covered with rocks. Pathfinder's mission was to study the Martian climate, atmosphere and geology. At the same time, the mission was also testing lots of new technologies.

For example, the Pathfinder mission tried a brand-new way of landing on Mars. After speeding into the Martian atmosphere, Pathfinder used a parachute to slow down and drift toward the surface of the Red Planet. Before landing, Pathfinder inflated huge airbags around itself. The spacecraft released its parachute and dropped to the ground, bouncing on its airbags about 15 times. After Pathfinder came to a stop, the airbags deflated.

Before Pathfinder, spacecraft had to use lots of fuel to slow down for a safe landing on another planet. Pathfinder's airbags allowed engineers to use and store less fuel for the landing. This made the mission less expensive. After seeing the successful Pathfinder landing, future missions used this airbag technique, too!

The Mars Pathfinder lander took this photo of its small rover, called Sojourner. Here, Sojourner is investigating a rock on Mars. Image: NASA/JPL-Caltech

Pathfinder had two parts: a lander that stayed in one place, and a wheeled rover that could move around. The Pathfinder lander had special instruments to study Martian weather. These instruments measured air temperature, pressure and winds. The measurements helped us better understand the climate of Mars.

The lander also had a camera for taking images of the Martian landscape. The lander sent back more than 16,000 pictures of Mars. Its last signal was sent to Earth on Sept. 27, 1997. The Pathfinder lander was renamed the Carl Sagan Memorial Station. Carl Sagan was a well-known astronomer and science educator.

Pathfinder also carried the very first rover to Mars. This remotely-controlled rover was about the size of a microwave oven and was called Sojourner. It was named to honor Sojourner Truth, who fought for African-American and women's rights. Two days after Pathfinder landed, Sojourner rolled onto the surface of Mars. Sojourner gathered data on Martian rocks and soil. The rover also carried cameras. In the three months that Sojourner operated on Mars, the rover took more than 550 photos!

Pathfinder helped us learn how to better design missions to Mars. It gave us valuable new information on the Martian climate and surface. Together, these things helped lay the groundwork for future missions to Mars.

Learn more about the Sojourner rover at the NASA Space Place: ***https://spaceplace.nasa.gov/mars-sojourner***

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