Air and Space this Week

Item of the Week

FRANK DRAKE, PROJECT OZMA, AND THE SEARCH FOR EXTRATERRESTIAL INTELLIGENCE

Originally appeared April 1, 2024

KEY WORDS: Frank Drake Drake Equation Project Ozma SETI Exoplanets

"Are We Alone?"

That's one of the "biggest-picture" of big picture questions facing Science. The first serious attempt to listen for radio signals (leaking) from a technologically-advanced alien civilization, Project Ozma, began on ***April 11, 1960, sixty-four years ago in a couple of weeks****. It was the brainchild of astronomer Frank Drake, and it was the start of Humanity's attempt to find out if life that developed technology that we could detect here on Earth could have arisen elsewhere!*

A PHILOSOPHICAL INVESTIGATION

The question of life, especially intelligent life, arising elsewhere not only is scientific in nature, it touches on philosophy, religion, sociology and more. There are so many stars and planets out there, and so many places life might have arisen, that it seems to some that the Earth could not possibly be the only place teeming with life of some sort. Were the conditions on Earth so unique that we are, indeed, alone? We just don't know (yet). Admittedly, the conditions that nourish life on Earth are many, and they had to occur in the sequence they did, but with so many planets …

One of the reasons NASA is concentrating on Mars and places like Europa is to determine if they are, or have been in the past, more clement to life. If we find that the environment that could support life arising occurs or has occurred on other places in our own Solar System, then it seems inconceivable that such places are not abundant, literally, universally, given the number of exoplanets out there.

The Earth is unique, or the prospects for life are relatively common; there seems to be no middle ground. We lack the technology to explore potential habitats close to home, so the question was more-or-less moot – at first. But there was a way to begin the investigation into the prospect of intelligent life elsewhere, if civilizations like ours arose there. And the scientist that led the way was …

FRANK DRAKE

Frank Donald Drake was born on May 29, 1930, in Chicago. His father was a chemical engineer employed by the city. Young Frank developed an early interest in science, especially astronomy, chemistry, and radio, and enjoyed frequent trips to the Chicago Museum of Science and Industry, not far from his home.

Frank started a life-long relationship with Cornell University when he matriculated there a few years after V-J Day, graduating 1952 with a B.S. in Engineering Physics (with honors). His education was provided via an ROTC scholarship, and after graduation, he received a commission in the U.S. Navy, where he spent three years as an electronics officer on the *U.S.S. Albany* (CA-123). His duties included training in cryptography, which would serve him later in his academic career.

After his Naval service, Frank enrolled in graduate school at Harvard, with the intention of becoming a professional astronomer. The academic credentials of his professors were quite impressive; he trained under Thomas Gold, whose academic lineage included Fred Hoyle, Paul Dirac, Wolfgang Pauli, and Wernher Heisenberg; Bart Bok; and Cecelia Payne-Gaposchkin, whose academic lineage included Harlow Shapley and Henry Norris Russell.

Radio astronomy was in its infancy in those days, and with his Navy experience, undergraduate education, and mentors of the caliber just described, he was well-positioned. One of the first things he did as a graduate student was to support the operation of Harvard College Observatory's new 60-foot radio telescope at HCO's Agassiz Station.

Dr. Drake received his Ph.D. from Harvard in 1958; his dissertation was about searching for neutral hydrogen in galactic star clusters. Neutral (non-ionized) hydrogen atom emits energy with a wavelength of 21 centimeters when the spin of its electron "flips" from being aligned with the spin of the proton to being opposite of it. Energy at that wavelength penetrates intervening dust well, so a radio telescope is ideal for mapping hydrogen in interstellar/intergalactic space.

Dr. Drake then became an early addition to the newly-created National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia. He proved to be as adept at administration and fund-raising as he was with radio astronomy, and quickly made a name for himself. His radio studies of Venus showed it to be much hotter than expected and Venus' unusual and slow retrograde rotation. He capped this phase of his career with the authorship of an important paper for the Proceedings of the National Academy of Science about the status of radio astronomy in the United States and its potential for future research.

His career was flourishing, but his growing family was dissatisfied with life in rural West Virginia. His family said "Californy is the place we outta be," so he loaded up the car in 1963 and moved to er…, JPL, where he had the plum assignment of being the Chief of Lunar and Planetary Science at the Jet Propulsion Laboratory. The position was more management than research, so he jumped a year later for an astronomy professorship at his alma mater, Cornell, where he later would head the Astronomy Department. His teaching and research went very well, and the field of radio astronomy was growing rapidly everywhere, but especially at Cornell. He

became the first Director of the National Astronomy and Ionospheric Center, stationed at the new 1000-foot radio telescope at Arecibo, Puerto Rico.

The primary research function at Arecibo was not radio astronomy but rather the study of the characteristics and behavior of Earth's ionosphere. The 1000' dish was set up to optimally operate at a wavelength of 68 centimeters, significantly longer than the wavelengths more important for astronomy, like the 21 cm he worked with as an undergrad. Not to worry, Frank pushed for, and got, a major upgrade to the 1000' dish that would allow the detection of the desired wavelengths. When pulsars were discovered in 1968, Drake was able to use the upgraded Arecibo facility to make important observations of them.

One of Drake's first undergraduate astronomy courses at Cornell had significantly affected his career. His imagination had been fired by a series of lectures by a visiting scientist, Otto Struve, who would later be his first boss at Green Bank when Frank was there. Drake had become enamored by the idea of using radio telescopes to eavesdrop on radio emissions from extraterrestrial civilizations, knowing that human activity such as high-powered search radars and radio broadcasts could easily be detected at interstellar distances. Time-delay for signals from such a distance would preclude a two-way communication, but there was enormous value in knowing other intelligent life was "out there."

The tools he would need for such a search were readily available at Green Bank, and Frank received a favorable response from Struve in early 1959. However, both were concerned that "looking for little green men" might not receive such a favorable response from their colleagues and their funding managers, so they resolved to monitor two stars for intelligent signals on an *ad hoc* basis. Always imaginative, Drake would name this effort after L. Frank Baum's Princess of the land visited by Dorothy and friends…

PROJECT OZMA

Drake and Struve need not have worried. In September, 1959, Guiseppe Cocconi and Philip Morrison published a paper in the prestigious scientific journal, *Nature*, entitled "Searching for Interstellar Communications." This was just what Drake and Struve had been planning to do! What Frank did next could be considered the birth of the Search for Extraterrestrial Intelligence.

Starting on **April 11, 1960, sixty-four years ago in a couple of weeks**, Drake used the 85' radio telescope at NRAO Green Bank to monitor two stars, Tau Ceti and Epsilon Eridani, for a total of six hours per day, scanning a range of frequencies searching for a non-natural signal. Those two stars were chosen because they are both relatively-close to the Sun (11 light-years) and both are more-or-less the Sun's size. The 21-cm wavelength (frequency 1420 MHz) was chosen because it's the neutral hydrogen line, perhaps likely to be ideal for "hailing frequencies" or ET usage. Still concerned about ridicule or financial repercussions, Drake used equipment already at NRAO. The Ozma Project ran until July, 1960, and had a total cost of about $2000.

Alas, no artificial signals were detected, but Ozma did inspire a lot of people, including one scientist-in-training, Carl Sagan!

SIDEBAR: THE SEIVE OF ERATOSTHENES

One of my personal favorites of the Greek scientist/philosophers is Eratosthenes. His name is fun to say, but good ol' Eratosthenes was no lightweight when it came to math and science. He was one of the string of librarians at the Great Library of Alexandria, and his ingenious – and accurate! - determination of the circumference of the Earth was the stuff of legend, and a whale of a good book, *Circumference*, by Nicholas Nicastro. [Bad Dad joke: "Who was the most important Knight of the Round Table?" Gawain? Nope. Bedivere? No. Gawain? Not really. 'Twas Sir Cumference! Groan. Sorry!]

The beautiful crater on the Moon named for him is one of only two used to name geological ages of the Moon, Copernicus being the other.

Eratosthenes was a clever mathematician, too. He devised a sure-fire way to find "all" of the prime numbers, a process that has become known as the "Sieve of Eratosthenes." If one took all whole numbers, then eliminated those that were divisible by two, then took the remainder and eliminated from them those numbers divisible by three, and then took the remainder after that and then eliminated all those divisible by five, and then took the remainder and continued this process, the numbers remaining would be the set of prime numbers. Primes, I'm given to understand, are useful in cryptography, so this process in the days of super-computing has been carried out to a rather large number of iterations. But the basic idea of the Sieve: Start with all and then systematically remove subsets until only the desired result is remaining, is the same process used in …

THE DRAKE EQUATION

The brief Project Ozma yielded no results. Undaunted, Frank Drake convened an invitation-only meeting at Green Bank, co-sponsored by the National Academy, to discuss the prospects for extra-terrestrial life, especially those who had technology we could detect. He was disappointed in Ozma's null result, but realized that he had listened in to only two stars of all the millions and millions in the Milky Way. Technology-capable civilizations could be extremely rare in our galaxy, but with so many stars the odds were excellent that at least some of them had planets with technology-possessing life.

Drake prepared thoroughly for the meeting. He wanted to at least roughly estimate how many tech civilizations there were in our galaxy, which would give an idea of how close one might be. To do so, he may-or-may-not-but-might-as-well-have took a page out of Eratosthenes' scroll to showcase those odds. The mathematical expression he came up with is now called the Drake Equation, part of his lasting legacy.

The Drake Equation, like the Sieve, starts out with everything and then systematically eliminates subsets of it. Here it is, in words: Take all the stars in the Milky Way, then remove those that do not have planets, then from the remainder remove all those that do not have planets in the "habitable zone," then from that remainder remove all those planets in the "habitable zone" all those whose planetary conditions precluded the arising of life, then from

the remainder remove those where life arose but did not result in complex forms, then from the remainder remove all those where life forms were complex but did not develop intelligence, then from that remainder subtract those where complex forms with intelligence that did not develop the technology (or interest) in interstellar technology. That would give the total number of civilizations that were capable and desirous for interstellar contact – over the lifetime of the planetary systems involved (a critically-important part of the analysis!). To get the number of such civilizations at any one time (today) the time span over which the civilization in question would remain technologically-capable and still-desirous of interstellar contact would have to be factored in.

Whew. It actually is easier to express this mathematically, multiplying the number of stars in the Milky Way by a series of coefficients (all likely to be less than one, except possibly for one factor) to get an estimate of the communication-able civilizations. Here is the Drake Equation:

$$\mathbf{N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L}$$

N is the number of technology-possessing civilizations in the Milky Way
R_* is the mean rate of star formation over the lifetime of the Milky Way
f_p is the fraction of the remaining total of stars that have planet systems
n_e is the average number of planets in a given system that are suitable for life
f_l is the fraction of suitable planets where life originates & evolves complex forms
f_i is the fraction where complex forms develop intelligence
f_c is the fraction of intelligent lifeforms who develop technology we can detect
and **L** is the length of time such civilizations emit signals we can detect

There are several ways the Drake Equation can be expressed, but the above is a good representative example. Drake could make reasonable estimate of R_* and N_e could not be a big number, most likely between 0 and 3. The other factors were quite unconstrained. The mathematical expression of the Drake Equation is sound, and we can now make better estimates of the value of its component factors, but there is still a LOT of variation possible in the number of civilizations out there we can overhear.

The two best examples of factors for which better estimates are available now are fp and ne. One of the great outcomes of the Kepler and TESS missions is the discovery that many if not most of the stars in our galaxy have planets (f_p is close to 1.0), at least the stars that aren't giants to begin with and those in late stage of life where they have expanded greatly. Another development that makes N trend higher is our better understanding of the "Goldilocks Zone," the area around a star where water could be liquid at least part of the time. As we are learning in our own Solar System, the Sun is not the only source of energy utilizable by life processes. For example, we find abundant life in anerobic conditions around deep-water hot springs.

Tides and tidal heating can also create environments amenable to life. Jupiter's three giant satellites (Europa, Ganymede, and Callisto); Saturn's Titan, Enceladus, and perhaps Mimas; Uranus' Triton; and perhaps even Pluto, all appear to have sub-surface bodies of liquid at depth beneath a crust comprised mostly of water and other volatile solids. There are bound to be places where deep internal tidal heating is making the icy crust liquid, akin to the deep-water springs on Earth. We know there are such on Enceladus, because we see eruptions of water vapor from cracks on its surface that are remarkably similar to cracks in terrestrial pack ice. The *Cassini* spacecraft, when its mission was near its end, was sent into one of the geyser-like plumes, and determined that the chemistry of the spewed material was similar to the material being released by terrestrial deep-water springs! So n_e, the number of planets/moons in a system that have "habitable" environments, could be not 0 – 3 but rather 0 – many.

The "L" term in the Drake Equation poses other questions and concerns. In our own case, L (to date) is an extremely small co-efficient – we've been detectable from afar less than a century out of the Earth's 4.5 billion years! Further, expressing civilizations this way caused Sagan and others to worry that L is short for all such civilizations, due to their development of weapons of mass destruction, rampant overpopulation, or other maladies that destroy their ability to communicate across the stars. The fact that we aren't finding intelligent signals could mean that L is too short for civilizations to live long enough for there to be many of them at any one time.

Interest in the "Are We Alone?" question cuts across national and political lines. Drake became the go-to international expert on what was being called the Search for Extra-Terrestrial Intelligence (SETI), publishing technical and popular papers and articles on the subject and inspiring a number of budding scientists to study the new field of astrobiology.

From an article on NASA Online: "In 1984, Frank moved to California to become dean of the Division of Natural Sciences and Professor of Astronomy and Astrophysics at the University of California, Santa Cruz, where he oversaw the science and engineering programs, continued to teach astronomy classes, and maintained his active involvement in the SETI program at NASA's Ames Research Center. He chaired the NASA SETI Working Group Report intended to formulate a national strategy for SETI research, and when NASA was no longer able to actively search for extraterrestrial intelligence, he became the president of the new non-profit SETI Institute's board of trustees and later the Institute's director of the Carl Sagan Center for Research."

TAKING A MORE DIRECT APPROACH

Eavesdropping on the radio communications of a distant alien origin is one way to search for extra-terrestrial intelligence. But it is not the only way!

Rather than operate on a "we can hear them but they can't hear us" basis, Carl Sagan hit on the clever plan to put plaques on spacecraft that were planned for a solar-escape speed and trajectory. First were *Pioneers 10* and *11*, the first to be launched to escape Sol's dominance, with an *en route* fly-by of Jupiter, and by Jupiter and Saturn, respectively. They each carried a plaque that was designed by Frank, Carl, and Linda Salzman (Carl's wife at the time). Then

came the two *Voyagers*, *1* and *2*, with not only a plaque, but a record and stylus of the "Sounds of Earth." *Voyager 1* discovered Jupiter's tiny ring system and the (spectacularly-predicted) active volcanoes on Io, then flew by Saturn. *Voyager 2* took the "Grand Tour," flying by all four gas giants, and giving us our only close-up looks to date of Uranus and Neptune. The fifth, and so far final, escapee is *New Horizons*, visitor of the Pluto/Charon system and the KBO Arrokoth. Mission PI made the decision not to include a message to any potential ETs who might come across it someday.

Frank Drake took a more direct approach. In 1974, after the Pioneers' launch but before the Voyagers, he arranged to send the "Arecibo Message," a digital greeting card, towards the globular cluster, M13, some 25,000 light-years distant. The signal was quite powerful, and with the 1000' antenna, could be detected by an as-capable counterpart anywhere in M13 if it were looking our way. Who knows? We may get an answer back some time around 49,950 years from now…

Drake served on many committees, advisory and scientific boards, and other activities worthy of a great contributor to Science. He won a large number of awards and accolades for his wonderful career. One of his last projects was to be on the advisory board for the Breakthrough Listen project, which uses much more-modern equipment to eavesdrop on potential techno-signatures from an advanced civilization.

Frank Drake passed away at his home, on September 2, 2022, at the age of ninety-two.

SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

Frank Drake's legacy lives on with the SETI Institute. The Institute was founded in 1985, with Thomas Pierson as its CEO and Dr. Jill Tarter has its principal scientist. Frank Drake was one of the four founding Trustees for the new organization. There have been a few changes over the years, but today SETI comprises the Carl Sagan Center, which manages among other things the SETI research programs under the leadership of noted scientist Nathalie Cabrol, and an aggressive and comprehensive education and outreach program menu. For more information on the SETI Institute, see: https://www.seti.org.

Various other organizations and programs are involved with the search of extraterrestrial life. While it would be amazing to get a calling card from afar, remember, the discovery of simple, or even fossil, life elsewhere would have a profound effect on every one of us!

And that is why NASA is involved in a major way ….

FROM THE DANGERFIELD ZONE TO A NASA PROGRAM

Frank Drake and Otto Struve were right when the soft-pedaled their initial SETI program, Project Ozma, out of fears that their colleagues and funders would consider such a thing a waste of time and money. The search for extraterrestrial life received no respect.

Things changed somewhat in 1996.

MARTIAN MICROBES ON EARTH (?)

The fact that a few of the meteorites that make their way to Earth actually came from Mars, blasted off that planet by a big, but glancing, impact event, picking up and incorporating atmospheric gases in the process had come out recently. That certainly was an extraordinary claim, but the trapped gases within matched the know composition of the martian atmosphere so closely that the idea of Mars bits on Earth was rapidly adopted by the planetary science community. Such is the value of "extraordinary evidence!"

More detailed analysis of one of the Mars meteorites, designated "ALH 84001, led a group of scientists to publish a paper in the prestigious journal *Science* in 1996, entitled, "Search for past life on Mars: Possible relic biogenic activity in martian meteorite ALH 84001."

The authors describe four lines of evidence that led them to the possibility of ancient microbial life on Mars. They were up front about the weakness of their evidence and conclusion, but pointed out that the "microbial life" hypothesis was supported or at least allowed by the observations. Each one of the four lines had an abiogenic explanation, but all four lines together, they judged, justified their hypothesis (recall your scientific inquiry, a **hypothesis** is an explanation that accounts for some of the results of observation and experimentation, while a **theory** is one that well-explains all observations and experiments). A theory is not a "wild guess," as so many believe; a theory is an explanation that has a lot of supporting evidence. After all, "Gravity" is only a theory. Don't test your disbelief in it by jumping off a cliff!

Unlike the "Mars bits on Earth" theory, which has very strong evidence support and general acceptance, the "Mars (once) had microbial life" hypothesis is an extraordinary claim without a correspondingly-extraordinary body of evidence supporting it, and is not generally accepted.

The effect that the publicity surrounding the "microbes" paper was quite interesting. As mentioned earlier in this Item, the independent development of life, any life, not just intelligent life, has profound implications not only for Science, but for philosophy, religion, and human affairs of all kinds. Some religions were aghast at the implications of life possibly arising elsewhere, not likely to be akin to their guiding documents/accounts. The Pope was very happy, because he saw it as yet another manifestation of God's benevolence in the Universe. It really got people's attention, that is one reason why the study of potential reactions to a real detection of extraterrestrial life is the subject of a NASA study (see below).

For a more complete treatment of the microbes issue, see here.

NASA'S EXOPLANET EXPLORATION PROGRAM

The huge amount of interest in the possibility of extraterrestrial life, and our growing technological capability of detecting exoplanets and actually learning something about them in detail, has led NASA to create and support its Exoplanet Exploration Program.

From the NASA ExEP website: The NASA ExEP "*science and missions represent an undertaking of unprecedented scope and ambition, promising insight into humankind's most timeless*

questions: What kinds of planetary systems orbit other stars in our galaxy? How common are solar systems like our own? What are exoplanets like? Are we alone?

"The primary goals of these explorations are to take a census of planetary systems in our galaxy, characterize the diversity of other worlds, and search for solar systems like ours. Ultimately, we aim to discover and characterize Earth-like planets around our nearest neighbors, search for habitable conditions on those planets, and uncover signatures of life. These investigations and the missions that carry them out are designed to build on each other's success, each providing an essential step forward toward the goal of discovering habitable planets and providing definitive evidence of life beyond our solar system."

Well Frank, we've come a long way, baby!

REFERENCES

Drake, F.D. and D. Sobel, 1992, *Is Anyone Out There? The Scientific Search of Extraterrestrial Intelligence*, New York: Delacorte Press, ISBN-13: 978-0385311229 (paperback)

The Drake Equation: https://exoplanets.nasa.gov/news/1350/are-we-alone-in-the-universe-revisiting-the-drake-equation

Sagan C., Sagan L.S. and F.D. Drake, (1972), A Message from the Earth, *Science*, v. 175, n. 4024, p. 881-884. Available here: https://astro.swarthmore.edu/astro61_spring2014/papers/sagan_science_1972.pdf

Arecibo Message: https://en.wikipedia.org/wiki/Arecibo_message

Frank Drake Physics Tree: https://academictree.org/physics/peopleinfo.php?pid=271519

Frank Drake Astronomy Tree: https://academictree.org/astronomy/peopleinfo.php?pid=271519

Frank Drake *Cornell Chronicle*: https://news.cornell.edu/stories/2022/09/frank-drake-51-astronomy-pioneer-dies-92

Frank Drake NAS: https://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/drake-frank-d.pdf

National Geographic article: https://www.nationalgeographic.co.uk/space/2020/06/my-dad-launched-the-quest-to-find-alien-intelligence-it-changed-astronomy

Frank Drake wikipedia: https://en.wikipedia.org/wiki/Frank_Drake

SETI Institute: https://www.seti.org

SETI: Project Ozma: https://www.seti.org/project-ozma

OTHER SETI-RELATED ITEMS IN A+STW

There are a number of items in this installment of Air and Space this Week about exoplanets that are more-or-less Earthlike and/or the search for extra-terrestrial life. I have put copies of them immediately below. Enjoy!

Could Evidence of Life Elsewhere Be Detected by the *Europa Clipper*? We know that several of the bodies in the outer Solar system have extensive, even global, liquid oceans under their icy crust. The surfaces of two, Jupiter's Europa and Saturn's Enceladus, have surfaces that in part resemble fractured pack ice on Earth. Some of Enceladus' surface cracks are spewing a geyser of liquid, mostly water, from below, the droplets of water quickly freeing. The *Cassini* spacecraft, near the end of its operational life, was directed to fly through on such plume. Its instruments showed the water had a chemistry similar to that on Earth around a deep-water hot spring; all known such springs on Earth harbor a number of environment-specific life forms.

A recent study of how effective the *Europa Clipper*'s imaging system would be if it targeted a geyser plume in detecting biological chemistry in its component ice crystals. Experiments show a bio signature could be detected if even only 0.1% of the crystals imaged contained the bio material. For a summary of this interesting possibility, see: https://www.sciencedaily.com/releases/2024/03/240322145406.htm, and for the paper itself in *Science Advances*, see: https://www.science.org/doi/10.1126/sciadv.adl0849.

SEARCH FOR HABITABLE EXOPLANETS

***Habitable Worlds Observatory*:** Yes, Virginia, there will be such a thing in the future. The 2020 Astronomy Decadal Survey strongly recommended that NASA "develop a 6-meter Space telescope capable of high-contrast observations in optical, infra-red, and ultraviolet wavelengths." Its primary mission will be to examine 25 different exoplanets in detail, all in their star's "Goldilocks Zone," searching for biosignatures. Knowing which stars to choose is obviously of great importance. That work is presently underway; NASA's Exoplanet Exploration Program has developed a list of 164 candidates to date, based on five selection criteria: stellar composition, photometric values, flare rate, variability, and potentially-sterilizing X-ray emissions. For more information on this project, see: https://phys.org/news/2024-01-astronomers-habitable-worlds-observatory.html and https://science.nasa.gov/astrophysics/programs/habitable-worlds-observatory.

SEARCH FOR INTELLIGENT LIFE ELSEWHERE

Part 1: UCLA's Jean-Luc Margot is the founder of UCLA SETI's "Are We Alone in the Universe?" project. Their mission is to detect "technosignatures by searching individual systems. Dr. Margot teaches a graduate course in SETI, and he had his students use *TESS* data for the closer known exoplanets to narrow the search for such emissions in great detail. No provable technosignatures were seen. Even though the smally sample observed didn't show emissions, the skills developed by the students (*e.g.* signal processing, telecommunications, and statistics and other data analysis tools) will no doubt improve their academic success.

Part 2: Traditional SETI tactics, like Dr. Margot's project, is one way to search. The Breakthrough Listen program (which uses citizen scientists) takes a different approach. Rather than look at relatively-close systems, they are using the Green Bank (West Virginia) and Parkes Murriyang radio telescopes to look for very high powered technosignatures, an entire galaxy at a time. For more on this program and strategy, see: https://phys.org/news/2023-12-breakthrough-scans-entire-galaxies-extremely.html.

Part 3: NASA has produced a six-part on-line series on how it is searching for life in the cosmos. If you are interested in the *real* science behind this topic, then check out these episodes! Part 1: Beginnings: Life on Our World and Others; Part 2: Life on Other Planets: What is Life and What Does It Need?; Part 3: The Hunt for Life on Mars – and Elsewhere in the Solar System; Part 4: "Life" in the Lab; Part 5: Searching for Signs of Intelligent Life: Technosignatures (see also this week's Gravity Assist entry in the Solar System section); and Part 6: Finding Life Beyond Earth: What Comes Next?

What Happens After We Discover Life Elsewhere? Mary Voytek, Director of NASA's Astrobiology Program, has some interesting thoughts on the subject. Check them out at: https://exoplanets.nasa.gov/news/1766/finding-life-beyond-earth-what-comes-next!

Exoplanet Travel Bureau is NASA's source for whimsical travel posters showcasing various exoplanets as tourist destinations and other exoplanet information. See: https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau!

Drake Award: The SETI Institute has awarded the 2023 Drake Award, which recognizes outstanding achievements in furthering understanding of the potential for life elsewhere in the Universe, to NASA's John Rummel. He was cited for "extraordinary and innovative programmatic contributions and unwavering advocacy for SETI and astrobiology." For more, see here and here.

Two Water Worlds, Too (Maybe): An astronomer team has found two exoplanets in a system 218 light-years away that appear likely to be composed largely of water. The Kepler-138 planetary system has two planets a bit larger than Earth, with three times the volume but only twice as much mass. No chemical analysis of their surfaces has been made to date, but estimates of their density, if true, require them to have a composition of something much less dense than rock; water being the most likely candidate. For more on this system, see: https://phys.org/news/2022-12-montreal-astronomers-exoplanets.html. Now please excuse me as I have a Robert Forward Rocheworld flashback …

More Evidence from Jezero! The *Perseverance* rover recently completed its 1000th sol on the martian surface. It has been exploring the floor of Jezero Crater and the delta and lacustrine (lake) deposits within, finding both carbonates and phosphates, indicative of a past environment quite conducive to biological activity. For more info on this mission and its ongoing success, see: https://www.jpl.nasa.gov/news/nasas-perseverance-rover-deciphers-ancient-history-of-martian-lake.

But Wait, There's More Evidence from Jezero! The Jezero landing site was deemed the most important single place to have a rover explore, because it was rather obvious from orbital data that a lake had once existed in the crater and a river had brought in (at least some of) the water that filled it, building a large delta in the process. *Curiosity* was not sent there because the landing site was a bit risky, a similar once-filled lake site at Gale Crater was chosen instead. Jezero's scientific potential, and our improved confidence in the sky-crane landing system, made it the target for the *Perseverance* rover.

Assessing the potential for paleo-life requires more than data acquired from orbit or even from looking at surface features; being able to determine subsurface details is important. *Percy* carries a ground-penetrating radar and has been examining the edges of the delta deposits for some time now. The data show that the crater's original floor had experienced some erosion before the lake was established, and two distinct periods of deposition and two distinct periods of erosion of lake sediments. The sedimentation pattern reveals that there were large-scale changes in the martian surface environment. For a summary of this work, see: https://phys.org/news/2024-01-ancient-lake-mars-perseverance-rover.html; for the paper in *Science Advances*, see: https://www.science.org/doi/10.1126/sciadv.adi8339.

Underground Oceans and Life: Worlds with subsurface bodies of water are found throughout the outer Solar System. At least some of them have volcanic activity at their bottoms. What are the implications for life in such environments? If such habitats develop, they will be difficult to detect from afar; how does that affect the search for extra-terrestrial civilizations? For more on this topic, see here.

***Cassini*'s Final Gift:** The Cassini mission to Saturn, a joint endeavor by NASA, ESA, and the Italian Space Agency, was an overwhelming success. Its orbiter component returned large amounts of image and other data during its 13 years in orbit, and its *Huygens* probe that soft-landed on Titan returned a lot of information about the only moon in the Solar System to have an appreciable atmosphere. When the *Cassini* orbiter was about to out of attitude-control fuel, its was flown on a risky path through plumes of water vapor being spewed from fissures on Saturn's moon, Enceladus, and then on a daring Grand Finale, flying beneath the great ring system. In its last moments of communications with Earth, *Cassini* relayed data that showed much more mass than previously thought were falling from the rings into Saturn. That, and other evidence, has led some scientists to propose that Saturn's ring system is astronomically very young, on the order of 100 million years or so.

Hmmm. All four gas giants have a ring system, with only Saturn's being a showpiece. Might it be possible that disruption of moons to form short-lived rings are a more ubiquitous planetary process than previously supposed? For more on this hypothesis, see here; for the paper in *Icarus*, see here, and in the following article.

Forget the *Fountains of Titan* – *JWST* Observes the Fountains of Enceladus! Kurt Vonnegut's second novel, *The Fountains of Titan* (1959), was referenced by Al Stewart in 1971's song of a similar name (see this week's Didja Know? section). Jupiter's moon, Europa, and Saturn's

moon, Enceladus, both are covered with a high-albedo fractured surface that looks for all the world like a terrestrial ocean ice pack, and for good reason, that's what it is. Many of the icy moons in the outer Solar System may have liquid oceans under a heavy cover of ice, kept liquid due to the action of tides, but Europa and Enceladus are the most blatant examples. Enceladus even has geyser-like plumes of dirty water they have been seen spewing above some of its surface fractures, and the *Cassini* spacecraft was even sent to pass through one such plume, sample it, and relay compositional information back to Earth. *Cassini*'s gone now, but Enceladus was recently observed by the *JWST*, and detected a plume of water vapor extending 6,000+ miles above the surface of Enceladus. That's one energetic geyser! For more on the *JWST* Enceladus observations, see: https://phys.org/news/2023-05-webb-telescope-towering-plume-saturn.html.

Uranian Moons Harbor Subsurface Oceans: The National Academy's 2023 Planetary Science and Astrobiology Decadal Survey identified the further exploration of Uranus and its larger moons as a priority goal. NASA has only visited Uranus once before, a fly-by by the *Voyager 2* spacecraft in January, 1986 (the excitement the real-time release of the images of the fly-by is related here). The need for information to assist planning the recommended mission led scientists to revisit the 37-year-old data. Computer modeling not possible back then shows that the four largest moons (Ariel, Umbriel, Titania, and Oberon) are large enough to have Uranus' gravity generate internal tidal heating that could lead to their having a subsurface ocean of liquid, likely water. This is the same mechanism driving internal geologic processes on Jupiter's large satellites and Saturn's Titan. For more information on this study, see: https://www.jpl.nasa.gov/news/new-study-of-uranus-large-moons-shows-4-may-hold-water.

Mimas Joins the "Moons with Subsurface Oceans Club!" Wow! When planetary scientists first saw close-up images of Jupiter's moon, Europa, and Saturn's moon, Enceladus, they were deeply suspicious that both had a deep, liquid ocean with a thick ice cover. That proved to be correct, with the reason for them having an underground ocean was the same tidal heating mechanism proposed for Jupiter's moon, Io, which was proven so dramatically when *Voyager 1* fly by it (see more of that story here). Subsequent studies have shown that two of Jupiter's other large moons, Ganymede and Callisto, also have large underground bodies of liquid (mostly) water. Saturn's large moons, Titan and Enceladus do, too. The *Cassini* spacecraft even flew through plumes of water spewing from cracks on the surface of the latter (and found chemistry akin to that of "black smoker" hot springs in deep ocean locales on Earth – which by the way teem with life). And there is strong evidence that dwarf planets Ceres and Pluto; Neptune's large moon, Triton; and several of the moons of Uranus have them, too. All these bodies make quite a club!

A moon doesn't have to be big to have enough internal heating from tidal forces to make an underground ocean (but it helps). It turns out that a small moon can, too, provided it's close enough to larger bodies to be subject to sufficient tidal stresses. Planetologists analyzing the motion of Mimas, a small but close-in moon of Saturn, also has underground liquid water.

Last Edited on March 31, 2024