Scanning the Cosmos: The Search for Life in the Universe

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ABSTRACT

The utter vastness of the universe makes it seem possible, perhaps even very probable, that there is life thriving on other planets. The cosmos, governed everywhere by the same laws of nature, are teeming with the very material that composes the Sun, the Earth and human beings. Could there be other worlds like our own? Might life exist beyond this planet? To answer these questions, we must consider the specific environments and distinctive circumstances necessary for life to arise. With this information, the detection methods and tools able to scour the great expanse for signatures of life can be determined. They, in turn, can be utilized to gather further data, potentially leading to the discovery of new worlds and new beings.

KEYWORDS

Exoplanets, detection methods, extraterrestrial life

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SCANNING THE COSMOS

THE SEARCH FOR LIFE IN THE UNIVERSE

What is life? A seemingly simple question—yet a universally accepted, all-encompassing definition remains elusive. We must consider this fundamental question if we are to take on the challenge of searching for extraterrestrial life. Part of the challenge is that we have, for now, only on reference: Earth. Though terrestrial life seems impossibly diverse (consider the four biological families: archaea, bacteria, eukaryotes, viruses and all that they encompass), who is to say that life beyond our biosphere is not equally so, if not more? *(1)*

LIFE AS WE KNOW IT

Life on Earth has been shown to be the result of matter organizing itself on various scales and under specific circumstances *(2)* over an extended period of time. Though the specific mechanisms from which life sprung remains a bone of contention, it is known that for life to develop, certain elements are needed: carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur *(3)*. These elements, created through the Big Bang and stellar evolution, form the backbone of life, and exist far and wide in our universe.

For life to prosper on a planet, a long-lasting energy source such as a star is required. Even if this requirement is met, life can only flourish in what is called the circumstellar habitable zone:

a range of distances within which the radiative output of the parent star allows for liquid water *(4)*. The habitable zone of a star changes gradually with time—a consequence of stellar evolution. As the nuclear fusion processes that sustain stars begin to produce heavier elements, the central gas pressure changes. The star's output increases, which causes the star to become more luminous over time. This change in luminosity affects the habitable zone. The range of radial distances within which liquid water could be found throughout the entire lifetime of a star is called the continuously habitable zone *(5)*. Life on Earth exists in the Sun's continuously habitable zone. Life on another planet would likely be found in a similar environment.

Additionally, the size of the star must be taken into consideration. More than ninety percent of stars are smaller than our Sun., These smaller stars are less luminous and thus the habitable zone lies closer to the star. Any planets orbiting within this region would become tidally locked to the star, plunging one half of the planet in perpetual frozen darkness and the other in constant scorching light. It is difficult to imagine life in what we would consider such an inhospitable setting. Yet let us not forget the extremophiles of our own planet, found in what are traditionally considered severely hostile environments to living beings. In the case of stars larger than our own, the problem that arises relates to time. The average lifetime of more massive stars is relatively short. Consequently, there may not be sufficient time for matter to organize and evolve into life. Overall, fewer than ten percent of stars in the universe are of a suitable mass to sustain life: between 0.7 and 1.7 solar masses *(6)*.

SHELTER FROM THE COSMOS

What of the planets themselves? Not all planets are created equal. Ergo not all planets provide safe havens for life. A typical star system contains rocky inner planets and gaseous outer planets. Rocky planets tend to be more favourable environments for life, as there exists the possibility of water on their surfaces *(7)*. Many adhere to the theory that the first forms of life on Earth emerged from the primeval oceans. Therefore, importance has been placed upon finding water elsewhere in our solar system, our galaxy and the universe. Water, though necessary for life to arise, is not sufficient for life to thrive. A geologically active planet generates plate tectonics, which hold a crucial role in the carbon cycle. Moreover, geologic activity can provide protection for emerging life. The convective movement present within the molten outer core of such a planet produces a magnetic field that shields the planet and any emerging life forms from incoming solar and cosmic radiation *(8)*.

Other factors important to the habitability of a planet are its orbit's eccentricity and obliquity *(9)*. The amount of thermal energy a planet receives from a star on an annual basis is greatly influenced by the eccentricity of its orbit (a measure of the perihelion and aphelion distances). The more eccentric an orbit, the less hospitable the planet, and vice-versa. Obliquity, the angle between a planet's spin axes and its orbit, influences planetary climate. Depending on the degree of the angle, a planet could experience a multitude of different temperature conditions, some tailor- made to harbour life and others thoroughly unsuitable. An ideal obliquity is one that guarantees a climate befitting the survival of living organisms: not too hot, nor too cold. The obliquity of Earth is 23.5 degrees. Such an incline gives rise to the seasons, ensuring the habitability of all regions year-round. Hypothetically, if Earth's obliquity was more extreme, say near 90 degrees, a large area would become a barren wasteland. Still yet, there is the added influence of the obliquity's stability. Earth's obliquity has remained constant due to its steady relationship with the Moon, allowing life to flourish. Alternatively, the teetering obliquity of Mars (fluctuating between 0 and 60 degrees, currently 25 degrees) has produced a barren landscape, seemingly devoid of life.

Though life might seem to prefer rocky planets (like ours), do not discount the gas giants, for they have their use. In a planetary system, the gravitational influence of larger gaseous planets can reduce the incidence of comet and asteroid impacts *(10)* on the smaller inner planets. This is of significance, considering the frequency of such impacts in space (as evidenced by the multitude of craters on the surface of the moon) and the devastating destruction they can cause.

The development of life boils down to three key points: a stable source of energy such as stars, an Earth-like planet within the habitable zone and the presence of the elemental building blocks of life (C,H,N,O,P,S). One could consider these the framework of the practical search for life in the universe.

LOOKING AND LISTENING

Despite our best efforts (direct imaging, rovers, in situ experiments of the Viking Mars Landers, etc.) even the most promising candidates for life in our solar system have yet to provide proof. Luckily, beyond our own planetary system lies a great deal more to be discovered. According to the online Interactive Extra-solar Planet Catalogue, as of January 2012, a little over 700 extra-solar planets have been detected. This is no easy feat considering planets are much smaller and dimmer than stars, and therefore practically impossible to detect directly. Ingeniously, astronomers have devised a series of indirect approaches by utilizing the effects that planetary bodies exert on the stars they orbit.

The most effective methods are radial velocity and transit photometry. Radial velocity exploits the concept of the Doppler effect. A star orbited by a body experiences a gravitational tug that causes the star to wobble in a small circle or ellipse. Using very sensitive spectrographs, a periodic shift in the star's spectrum can be observed: a blue-shift as the star wobbles toward the observer and a red-shift as it wobbles away. If these shifts are observed regularly, then this is evidence of an orbiting body, perhaps even a planet. This method provides an estimate of an orbiting body's minimum mass, which can determine the nature of the body, planet or otherwise. Unfortunately, this method tends to detect types of planets least likely to have conditions suitable for life since small earth-like planets cause a relatively smaller and less easily detected wobble than their giant gaseous counterparts *(11)*.

Transit photometry measures the tiny dip in brightness of a star as a body passes in front of it. This body is most likely a planet if the diminished brightness moment occurs at regular intervals. The magnitude of the dip is proportional to the size of the transiting body. Combining mass and size data from both the radial velocity and transit methods provides information on the planet's density, which thus sheds light on its composition. Furthermore, the observed absorption spectrum of a transit infers the planet's atmospheric makeup *(12)*. All this information provides key insights into the habitability of a planet.

A third method, microlensing, can be used at much greater distances than radial velocity and transit photometry – thousands of light years away. The immense range of this technique becomes apparent when you consider that Pluto is mere light *hours* from us, whereas the diameter of the Milky Way galaxy is *hundreds* of thousands of light years across. Microlensing is the practical application of Einstein's General Theory of Relativity, which predicts the distortion of light waves due to gravity. When a star passes in front of a more distant star, it will act as a lens, distorting the light waves and amplifying the brightness of the distant star *(13)*. This amplification can last up to about a month, sometimes giving an orbiting planet enough time to reveal itself. In such cases, the telltale result is a momentary spike in brightness.

Astrometry is yet another indirect detection method. Similar to radial velocity, it infers the existence of an orbiting planet through the detection of a wobble. The distinction between the two techniques is that astrometry uses a star's wobble relative to its surrounding stars in the sky instead of to its orbiting bodies.

The detection methods described above demonstrate the creativity and enterprise present within the field of astronomy. However, they do not take into account the possibility of extraterrestrial intelligence equally imaginative and resourceful. We can painstakingly search the skies for planets like ours to get a better understanding of how hospitable our universe is, however, there may be a shortcut: If indeed there exist such beings elsewhere in the universe with similar cosmic agendas, then surely they would have, like us, harnessed the power of science and technology. Radio astronomy, the study of radio waves emitted by distant objects *(14)*, is an exciting tool in the search for extraterrestrial civilizations. Radio waves are not absorbed or scattered by interstellar gas, and thus can travel very large distances unimpeded *(15)*. Listening for radio signals from space garners a significant amount of noise from all regions of the electromagnetic spectrum. Fortunately, within this spectrum lies a comparatively quiet zone: the 21 cm line. Hypothetical advanced civilizations could most certainly use this range for communication. Radiotelescopes calibrated to the 21 cm line and pointed toward extrasolar planets would certainly pick up any extraterrestrial chatter, though this has yet to prove fruitful. Radio astronomy is one of our greatest resources in the search for intelligent life forms in the universe.

The beauty of the pursuit for life in the cosmos lies within the process. The scanning of the skies breeds a plethora of new discoveries and achievements. These in turn give rise to further innovation. Though we may never discover extraterrestrial life forms or achieve contact with intelligent alien civilizations, the knowledge amassed on this cosmic journey is never squandered. We must persevere. Carl Sagan said it best: "Imagination will often carry us to worlds that never were. But without it we go nowhere."

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