Scientific Insights into the Evolution of the Universe and of Life
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SCIENTIFIC QUEST INTO EVOLUTION OF LIFE IN THE UNIVERSE

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1. INTRODUCTION

The Big Bang Model of the Universe is now well established (Hawking 1983; Weinberg 1977; Spergel *et al.* 2007). Electrons, protons, neutrons were formed in the first few minutes, leading to the nearly 75% mass of hydrogen, 25% helium, and some light elements, that later cooled and gave rise to a visible mass of stars and galaxies. Theoretical models also predict heavier particles that are likely to be the constituents of the dark matter in the Universe. Radio astronomers have discovered over 100 molecules in the interstellar surroundings. Thus it seems likely that the initial electrical and chemical affinity of electrons and protons gave rise to increasingly complex forms on the Earth. However, it is yet not clear as to what processes resulted in the growth and appearance of the first cell with its ability for self replication. It is a challenging area of experimental science being pursued by many biologists, geneticists and others.

Our Universe is vast. There are billions of galaxies in our Universe. Each galaxy has billions of stars. Life may be widespread in the Universe. The possibility of searching for life in distant galaxies is a remote possibility. However, the search for life elsewhere in our solar system and also in planets with favourable conditions in our Galaxy is likely to be made by mankind using larger and more sophisticated instruments for decades to come.

In Section 2, possible scenarios for the origin of life on the Earth are discussed. Section 3 briefly summarizes scientific evidence for the evolution of life from extremophiles to mammals to mankind. The search for life elsewhere in our solar system is discussed in Section 4. As described in Section 5, astronomers have discovered 340 planets in nearby stars and this number continues to increase rapidly. Finally, the important question: are we alone? Section 6 describes endeavors by radio astronomers in the Search for Extraterrestrial Intelligence (SETI) that started with the pioneering effort by Frank Drake in 1959 using a relatively modest radio telescope and receiver system. Many SETI observations have been made over the last 50 years using larger radio telescopes. However, the sensitivity of existing radio telescopes is not sufficient to search for very weak signals from distant parts of our Galaxy. I describe in Section 7 new initiatives for SETI that would allow probing towards millions of stars. Optical SETI is briefly described in Section 8. Summary is given in Section 9.

2. Origin of Life on the Earth

Three main scenarios have been proposed for the origin of life on the Earth.

(a). *Did lightning and volcanoes spark life on the Earth?*

Soon after the formation and cooling of the Earth about 4.5 billion years ago, numerous large volcanoes and lightning occurred on the Earth that may have provided sufficient energy for the synthesis of molecules. In a famous experiment carried out in 1953, Stanley Miller, a graduate student of Harold Urey, put ammonia, methane, hydrogen and water in a sealed flask, applied electrical sparks and detected 5 amino acids that are some of the building blocks of proteins (Miller 1955). After Miller's death in May 2007, Dr. Bada, who was one of the graduate students of Miller, got access to a boxful of vials containing dried residues resulting from the various experiments carried out by Miller during 1953 and 1954. In 2007, Adam Johnston joined Dr. Bada's laboratory on an internship. Besides the apparatus known in textbooks, Miller also used one that generated a hot water mist in the spark-flask, simulating a water vapor-rich volcanic eruption. Johnston reanalyzed the original extracts of this experiment using modern techniques. The volcanic apparatus produced 22 amino acids including those that were not identified from the Miller-Urey experiment (Johnston *et al.* 2007). However, many doubts have been raised about this scenario for the origin of life, such as Earth's environment and its constituents 3.5 billion years ago that may not have been conducive to the growth of life.

(b). *Origin of Life in deep sea hydrothermal vents*

In recent years scientists have discovered a rich variety of simple forms of life (extremophiles: see Section III) in deep sea hydrothermal vents containing sulfides and other minerals. It is currently believed that these hydrothermal vents may provide a suitable environment where the building blocks first came together for the evolution of life gradually over millions of years.

(c). *Life forms on earth came from Outer Space*

Radio astronomers have discovered over 100 molecules in the interstellar medium. It may be that cellular life exists elsewhere in our Galaxy and could be carried far and wide by comets, seeding the planets in our solar system (hypothesis of panspermia). It is not clear whether such life forms will survive in comets over a long period against bombardment by cosmic rays containing very energetic protons. Nevertheless, the discovery of amino acids in some of the meteorites has suggested that the building blocks of life on the Earth came from outer space, eliminating the need for finding chemical processes that could produce pre-biotic material on Earth. Another possibility is that the meteorites carried life forms from a planet such as Mars in our solar system. However the organisms travelling on a rock ejected from one body in the solar system to another would be subjected to radiation, vacuum and extreme temperatures. Continuing exploration of planets and some of their satellites may find *none, same or different forms of primitive life therein, and thus discriminate between various models*.

3. Evolution of Life

It is a vast subject and has been discussed in detail by many authors in these proceedings (also in a textbook by Jones 2006). I give here a sketchy summary in order to postulate that there is a reasonable probability that life may exist elsewhere in our Galaxy.

Fossil records provide evidence that there existed RNA/DNA-protein life ~2.5 billion years ago. The origin of life took place much earlier. Its origin is likely to have taken place from the pre-biotic stage to the RNA world, but details are not clear and remain a scientific challenge. Tens of thousands of fossil records show that evolution took place from single-celled prokaryotes to eukaryotes that have long genetic codes. Evolution seems to have taken over millenniums by natural selection, adaptation etc. from cynobacteria, archaens, prokaryotes, to eukaryotes to fish to amphibians to reptiles to mammals, apes to homo sapiens. However, the genesis of the anaerobic first cell, the progenote of the RNA world is an open question.

Extremophiles: Bacteria have the potential to adapt and grow in extreme conditions (www.astrobiology.com/extreme.html; www.bacteriamuseum.org). Extremophiles include anaerobes, thermophiles, psychrophiles, acidophiles, alkalophiles, halophiles, barophiles and xerophiles. A wide variety have been found, e.g. in hot geysers in deep oceans, in hot springs at temperatures up to ~130 degree Celsius (hot springs of Yellowstone National Park and geothermal features all over the world); in soils or floors of the ocean with high salinity (Mediterranean); in ice at -60 degree Celsius (Antarctica), etc. It is quite probable that microbes may grow and thrive in other similarly hostile places in the solar system and elsewhere in planets of distant stars.

4. Looking for Life in Mars

Besides the recent landed missions on Mars, orbiting satellites by ESA and NASA have made photographic and spectroscopic exploration of outer planets and their moons, particularly of Mars, Jupiter and Saturn. In 2004, the scientists analyzing data of the Mars Express of ESA reported that they had detected methane in the atmosphere of Mars. Recently, astronomers have confirmed the presence of methane searching for the chemical 'fingerprints' in the spectrum of Martian atmosphere using an optical telescope in Hawaii. Some regions on Mars displayed higher concentrations than others. 'Is it geology, in which case it is the reaction between water and rock that is producing the methane, or it is biology, in which case the microbes are producing the methane?

NASA's 'Spirit' and 'Opportunity' vehicles that landed on Mars ~5 years ago provided spectacular scenery of many interesting geological features. The broken wheel of the 'Spirit' had a silver lining: it was digging trenches during its journey and some of these showed the presence of 90% silica, indicating evidence of water. NASA's Phoenix landed on Mars in May 2008 and has made extensive explorations. It has confirmed the presence of ice-water and also snow falling from Martian clouds. Soil experiments have provided evidence of past interaction between minerals and liquid water, processes that occur on the Earth. Now with the presence of methane, signs of life are getting even stronger. It would be extremely interesting to explore whether extremophiles, even archea or cynobacteria, extinct or even living, exist on Mars or elsewhere in the solar system.

5. Search for Extrasolar Planets (Exoplanets)

The first exoplanet was found in 1992 orbiting a radio pulsar by accurate timing. In 1995 Michel Mayor of the Geneva Observatory discovered a planet orbiting a nearby star by measuring very tiny shifts in the spectral lines of the star caused by Doppler shift due to the planet orbiting the star. The orbiting planet results in the star rotating about a common centre of gravity of all the masses, and is called the Wobble method. It easily detects gas giants comparable or larger than the massive Jupiter, though some smaller planets are also found. Besides the above method, several other techniques are being used for searching for exoplanets (Pudritz *et al.* 2007).

If the orbital axis of a planet lies nearly perpendicular to the direction of a star, we can observe its transit causing a decrease in the luminosity of the star's light, allowing measurement of its mass. Also the light from the star probes the atmosphere of the planet giving measurements of the nature of its gaseous contents. This is called the WINK method. Transit observations have been made of ~27 exoplanet. Another method used is to search for gravitational microlensing of far away planets towards a star. This method, though time consuming, has allowed detection of a near earth size planet from a far away star.

Nearly 340 exoplanets have been discovered so far, mostly by the Wobble method, including ~27 multi-planet systems, (www.obspm.fr/encycl/catalog.html). We are living in exciting times! New discoveries continue to be made every few months. On 20 March 08, methane was found in the atmosphere of an exoplanet; on 17 June 08, a trio of super-earths was found orbiting a nearby star, 42 light years away (4.2 to 9.4 earth masses); on 29 September 08, a planet of mass Mp = 0.53Mj with an orbital period of 3.7 days was discovered.

Over the next decade or two several thousand planets are likely to be discovered by space telescopes, such as Kepler (recently launched), COROT, Cassini, James-Web Telescope and many ground based telescopes, including the proposed Extremely Large Telescopes (ELT) of 30m in size in USA and 42m in Europe. In the future NASA's Terrestrial Planetary Finder and ESA's Darwin will seek Earth-size planets with temperatures ~300K. Highly sensitive spectrometers may discover signs of life by detection of methane and other constituents such as CO_2, ozone, oxygen, water, etc.

6. Search for Extra-Terrestial Intelligence (SETI)

In 1959 Frank Drake made a pioneering attempt using an 85ft radio telescope to search for any narrow band radio signals, presumably transmitted by an extra-terrestrial intelligent civilization. In 1959 he also postulated that the estimated number of civilizations in our Galaxy depends on a number of probabilities: the Drake Equation has 7 terms (Drake and Sobel 1967). In brief the estimate depends upon the assumed number of suitable habitable planets in our Galaxy similar to that of the Earth in the Solar system, fractions with advanced communication skills, their mean lifetime, etc. Estimates vary from one (rare Earth) to ~10000. Further it is not clear whether an advanced civilization will broadcast signals and if so in what form.

In 1959, Cocconi and Morrison suggested that a preferred frequency for SETI could be the natural emission line of the neutral Hydrogen at 1420 MHz, since Hydrogen is the building block of stars and galaxies. A distant civilization may choose some other frequency, or we may attempt to search for leakage radiation from their transmitters. There are technical reasons for searches to be carried out in the frequency range of about 1000 MHz to 10,000 MHz. This window offers a minimum in the value of the sky noise, consisting of the galactic background and atmospheric noise, and thus provides maximum sensitivity for a given radio telescope. It is called the water hole as it covers the frequency range of the line emission of neutral hydrogen, HI, and molecules OH and H_2O.

Over the last few decades radio astronomers have made general searches towards various directions of the sky, and more intensively towards selected nearby stars using available radio telescopes for any signals that may have been sent by an extra-terrestrial civilization. No signal has been detected so far. However, the sensitivity of existing radio telescopes is not sufficient to search far and wide. The results of searches made so far have helped in determining upper limits on the power flux density incident on the Earth from any ETI signal. Some of the most sensitive searches carried out so far are the following:

Southern sky: A decade ago, the SETI institute and Australian scientists carried out a search towards 200 solar type stars using the Parkes Radio telescope of 64m diameter in Australia, giving a detection sensitivity limit of ~10^{-25} W/m^2.

Northern sky: The University of Berkeley group is using the Arecibo Radio Telescope of ~200m diameter. They have surveyed ~800 solar type stars, reaching a sensitivity of ~10^{-26} W/m^2. The search is continuing. Data is also being analyzed using thousands of computers across the world (SETI@Home).

No signal has been detected so far from any transmitter that may be located up to a distance of ~100 light years away, radiating towards the earth, say with a power of 10 MW connected to an antenna of 60m diameter (such transmitters exist on the Earth).

7. New Seti Searches

7.1. *There are many technical challenges:*

Radio telescopes with much higher sensitivity are required with a large collecting area, multiple beams, wide bandwidth and a very large digital spectrometer. It can be shown that the signal of a transmitter *can be detected farthest away,* if the bandwidth of the receiver is very narrow, say 0.1 Hz (~CW signal). Alternatively one may search for wide band narrow pulses using a receiver with large bandwidth. Therefore, we require spectrometers with terra-Hz capability that is possible today as Moore's law continues to be valid! It is also important to note that modern technology allows SETI to be carried out simultaneously with normal astronomical observations, and thus we can search millions of potential stars with modest additional investments. I describe below some new initiatives.

7.2. *Allen Radio Telescope (ATA), USA*

ATA consists of a radio telescope array of 350 antennas of 6m diameter. The antennas and associated electronics provide high performance. ATA has been set up at Hat Creek in California by the SETI Institute and the University of California, Berkeley (www.seti.org/ata). Forty antennas that are funded by Paul Allen of Microsoft are operational. ATA provides a large instantaneous bandwidth of ~100 MHz, 200 million spectral channels and several antenna beams of its phased array, for simultaneous searches towards many stars. It covers the frequency range of ~1 GHz to 11 GHz (the water hole described earlier). The goal of the SETI survey with ATA is to investigate hundreds of nearby stars over a wide frequency range from 1 to 11 GHz, with adequate sensitivity to detect a transmitter equivalent of the Arecibo radar ($2x10^{13}$ W EIRP) located in a planet in a far away star. Another SETI survey of about 20 square degrees along the galactic plane in the direction of the galactic center will cover thousands of distant stars over a frequency range of 1420 MHz – 1720 MHz with a long integration time. At the distance of the galactic center, a detected transmitter would be radiating power equivalent to more than 25,000 Arecibo radars.

7.3. *The Giant Metrewave Radio Telescope (GMRT), India*

The Giant Metrewave Radio Telescope (GMRT) built in India has been in operation since 1999 (www.ncra.tifr.res.in). It is located ~80 km north of Pune in India. It consists of 30 nos. of 45m diameter dishes located in an array of ~25km in extent. It can observe over ~80% of the sky. It is currently the world's largest radio telescope operating in 5 frequency bands from ~130 MHz to 1430 MHz. GMRT is currently being upgraded and will provide nearly continuous coverage from ~40 MHz to 1430 MHz. Wide band feeds and low noise amplifiers are being installed. A software correlator with 32 MHz bandwidth has been installed recently and it will also provide multiple beams within a year. A software/hardware correlator with a bandwidth ~256 MHz or 400 MHz, with a large number of spectral channels, is planned to be completed over the next 3 years. In addition to providing cross-products of voltage outputs of all the 30 antennas for each of the spectral channels, as required for imaging, the GMRT correlator system also produces an independent output giving a sum of the voltage signals received by the 30 antennas of 45m diameter, making it equivalent to a 200m diameter dish, 5 times more powerful than any other radio telescope covering the southern sky. Therefore, the upgraded GMRT, providing an independent output of narrow band channels of < 1 Hz over tens of MHz, can be used for a SETI, simultaneously with the normal astronomical observations.

7.4. *Square Kilometer Array (SKA): a very challenging project in radio astronomy*

SKA will be ~100 times more powerful than any existing radio telescope (www.skatelescope.org). SKA is planned to be built, during 2012 to

2020, by 17 countries, including Australia, China, India, South Africa, UK, Netherlands, Italy, Canada, USA, Argentina and Brazil. It will have thousands of antennas to be located in an array of ~3000 km across. Already two independent pathfinders for the SKA are under construction in Australia and in South Africa for demonstrating technologies required for the SKA. SKA will be located in one of these two countries**.** It will be a very versatile instrument using advanced electronics. It is being designed to answer certain key questions, such as: ultra-strong field limit of relativistic gravity; origin of cosmic magnetism; galaxy evolution; epoch when first stars formed and also ETI. Over the next 20 years, the SKA will search towards millions of stars for any signals sent by an advanced civilization and also any leakage signals from their radars or fixed and mobile transmitters.

8. Optical SETI

It may be that an advanced civilization in our Galaxy may develop powerful lasers for interstellar communication. Considering the above possibility, searches have also been carried out recently using optical telescopes with receivers that are sensitive to pulses of very narrow time duration, of less than a millionth or a billionth of one second. However, atmospheric absorption and intergalactic dust may restrict communication over long distances.

9. Summary

Extensive scientific work has been done over the last 150 years concerning evolution of life on our planet. Valuable insights are being obtained using modern tools in paleontology, biology, bio-chemistry, genetics, neurosciences, etc. The origin of life remains a scientific challenge. Mankind has made great progress over the last ~10000 years, particularly over the last few hundred years. What is our future? We must continue to ensure that our civilization becomes more peaceful? *Is human intelligence also subject to Darwinism?* Do advanced civilizations become altruistic in order to be peaceful and not destructive of their surroundings?

Should we search? If we do not search how can we say that we are alone? Searching for life elsewhere in the solar system may give us new clues. Exciting developments are likely over the next decade from the discoveries of earth-like planets in distant stars, and planned observations of their bio-signatures. SETI with new radio instruments, such as ATA and SKA, upgraded GMRT, and optical SETI will allow us to search towards millions of stars.

Man has wondered for long about the origin and evolution of the Universe. More than 3000 years ago, sages in India wondered (Rig Veda: Chapter 10, stanza 129/1):

There was neither existence nor non-existence then,
Neither the world nor the sky that lies beyond it;
What lay enveloped? and where? and who gave it protection?
Was water there, deep and unfathomable?

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