Look for Life in Galaxy? Queen's/RASC Jan 14 14

Why is the search for extraterrestrial life a serious scientific experiment today? To get some sort of perspective on this, recall that ever since the Copernican Revolution of the Sixteenth Century men have realised that the Earth is part of the heavens. Far from being a body separate from and specially placed in the Universe the Earth is just one of a number of worlds orbiting the Sun. Modern astronomy has revealed to us an immense Universe. We know now that the Sun is one of about 100 billion stars in our own Milky Way galaxy and that the Milky Way itself is one of billions of galaxies. Furthermore, there is nothing obviously unusual about our environment. The Sun is in every way a fairly typical star and so today there is more reason than ever before to wonder if the phenomenon of life, because it exists in this very ordinary place, might not be widespread throughout the Universe.

This has led to considerable interest in carrying out searches for life. There are really two approaches to a search for life, as opposed simply to waiting for extraterrestrial life to show up here in the form of "little green men" emerging from UFO's, or something like that. The first approach is exceedingly direct. It consists of going and looking for life on the surfaces of other astronomical bodies. This is the approach of the NASA space program, and it is of course very expensive. It has the great merit that it can potentially detect life of almost any kind, even very simple microscopic life. It can detect life at almost any level of development provided that the life satisfies some criterion that is enshrined in the design of an experiment that we land on another planet. This very direct approach is however confined for the foreseeable future to the exploration of the planets of our own Solar System. The second approach, which is the one I am involved in, allows us essentially to cast our "search net" much wider in the Universe but at the expense of being restricted to much more advanced life, namely life that is capable of launching significant signal strengths across interstellar distances. This second approach - essentially "listening" for signs of life in the Universe - allows us to explore a much larger volume of space than does the direct "go-and-look" approach, but it restricts us to discovery of what I shall call Technological Communicative life. "Technological" here will mean "capable of transmitting detectable quantities of electromagnetic energy across interstellar distances" and "communicative" will mean "capable of and interested in coding signals in such a way as to convey intelligible information to us". These are rather restrictive definitions of "technological" and "communicative" but they will serve my immediate purpose here.

Life

Scientific study is biology and biologists I know find exact definition of life troublesome but can offer the following:

If matter exists within a boundary such that it is capable of maintaining, enlarging and reproducing its structure from within the boundary, given only a more generalised supply of energy and matter from outside, then the stuff in the boundary is alive.

Essence of life is ability to preserve, enlarge and reproduce its own structural order.

Order itself does not guarantee life. Simple (relatively) structure like virus particle is alive but newly dead whale is not. Ability to maintain order is vital. property.

This is remarkable because it means life must continuously oppose the general tendency of matter to disorder. Old buildings may collapse into heaps of rubble, but heaps of rubble never spontaneously assemble into structured buildings. Second Law of Thermodynamics fossilises such observations.
Order disappears in most spontaneous natural processes.

Life achieves its preservation of order by
- borrowing well-ordered energy from sources in environment ("food")
- manipulating borrowed energy to perform structural tasks within the life
- returning disordered energy to environment ("wastes").

Total system of sources, life and waste increases its disorder. The order within life is preserved at expense of disordering environment. (At the root of some of our fundamental human problems?)

Proliferation of species of Earth life does not correspond to proliferation of different mechanisms for this life procedure.

All Earth life uses same chemical machinery (essentially), based on ability of tertravalent carbon to form backbone of long chain or ring molecules on which complex chemical processes can occur. No organism on Earth is not based on carbon chemistry - hence name organic chemistry.

Basics: Carbohydrates - energy source
Fats - energy storage
ADP, ATP, - energy manipulation in cells
Proteins - define structure and facilitate reactions
Nucleic acids DNA, RNA - patterns for protein synthesis

Plus: WATER - universal solvent in which chemistry takes place
ionising solvent, facilitates reactions
hydrogen bonding loosely holds biomolecules while reacting
high thermal capacity, regulates organism temperature excursions

Other bases imaginable - silicon chains (silicones)
liquid ammonia at low T

But to be specific about life search will stick to LAWKI (no statistics possible). Point is that even search for LAWKI has high prob of success. so need to indulge in

Requirements of LAWKI to exist elsewhere.

Stable high-quality energy supply — starlight.
Solid / liquid / gas interface plus liquid - water — surface of planet (Apollo mimics this)
C, N, O, P, S, Fe/Mg — environment with some heavy elements.

Crucial questions determining probability of existence of LAWKI elsewhere.

1. Is chemical basis for LAWKI abundant through galaxy?
2. Are planets commonplace?
3. Given planets and chemistry, does life evolve anyway given time?
4. Is time provided by likely energy sources (stars)?

① Chemical basis.

LAWKI is based on elements some of most abundant in solar neighbourhood of our galaxy.

Element abundances are determined by processes of stellar evolution which synthesise heavy elements from primordial H/He mixture. First-generation stars in our Galaxy (halo population) poor in heavy elements, but explosive stages of their evolution distributed heavy elements into interstellar gas out of which second- and later-generation stars formed. So LAWKI chemistry is abundant, chemical mix determined by same nuclear physics throughout the Milky Way.

2) Planets? Ask about evolution of stars.

Stars form by gravitational collapse of spinning interstellar clouds. Collapsing clouds spin faster (skater effect) and material is centrifugally flattened into disk. If little else happened, all stars would be rapidly spinning disks. But direct observation shows that ~ ½ stars in galaxy are doubles.

So 50% probability that disks fragment → 2 stars whose mutual orbit takes up the spin of the disk.

Other 50% — single stars? Clue from Solar System! Angular momentum of Solar System is concentrated in orbital motions of planets, especially Jupiter. Seems likely that planets condensed from matter in spinning disk accompanying the proto Sun.

So it is *likely*, Sun being a typical single star in most measurable respects, that this is fate of most of the single stars. Evidence → most massive ones *are* in rapid rotation, but stars cooler than F5 have v. little rotation. *Expect* most stars cooler than F5 and not double stars to have planets.

Direct evidence for this is hard to come by. V. difficult to detect Jupiter as companion to Sun from 30 L.Y. away. But for most nearby single stars whose masses are small enough to be perturbed noticeably by Jupiter-like planets, there is some evidence for perturbations corresponding to gravity pull of unseen planetary companions. Best-discussed ~~documented~~ example is Barnard's Star (altho' not yet clear that this is real as most of data come from one telescope). These are *massive* planets, not "Earthlike". But encourages idea that planetary systems commonplace.

3). Evolution and Origin of life.

Origin of life on Earth still speculative ∵ we never see life appear in absence of life that already exists. Life never appears in entirely non-living matter (except in horror movies).

Fossil record shows that life evolved in complexity over ~ 3 billion years, beginning as simple microorganisms and marine plants. Natural selection (selective elimination) produced Man from microbes and blue-green algae. What started us off with micro-organisms is unknown. There are several *theories* however.

Theory 1. Spontaneous chemical assembly. On this theory, first living matter evolved by pure chance in primeval environment. Proponents of this idea have successfully demonstrated that random synthesis of organic molecules can occur in simulated primeval environments providing a) ∃ energy supply sufficient to rupture inorganic molecules

b) No oxygen to destroy organic molecules

c) Organic products *protected* from disruption by energy supply.

All 3 conditions likely to have been satisfied in oceans on primeval Earth with no oxygen in atmosphere → plants which eventually provide oxygen, cut off UV supply. Earth is only planet with O_2; O_2 came *after*

Especially fits in with marine origin of life as a few feet of water give exactly the needed protection from energy supply while permitting chemical activity among organic prods.
Simulating geologic time passage by concentrating products of synthesis experiments, have demonstrated build-up of simple carbohydrates, sugars etc.

fatty acids
aminoacid chains resembling proteins
ATP (if phosphorus present).

But this basic organic chemistry is not *life*. Life needs genetic code to maintain structures.
If self-replicating molecule of nucleic acid first formed randomly, the replication gives it thermodynamic advantage: can produce copies; second molecule don't have to be formed by same random procedure as first. Once formed, first could reproduce. But there are other alternatives to random formation of genetic code

2) Panspermia — genetic coding for life came to Earth on "seeds" or "spores" carried naturally (meteorites & dust) across i/planetary distances
Life can survive extremes. e.g. frozen seeds germinate
viruses dessicate but active in water later
bacteria in nuclear reactors
∴ Possibility that life in suspended animation could traverse i/ple distances is not absurd.
Odds of finding planet small.

3) Directed panspermia — Deliberate "seeding" by other life (death-throes, joi de vivre).
Accidental "seeding" — (cheese sandwich hypothesis)
Religious beliefs?

Either spontaneous evolution or directed panspermia suggest that life elsewhere may be common, if the time-scale for chemical evolution is available.

(4) Time. For main-sequence stars this is no problem. Lifetime longest on MS, exceeds genesis time for Earth life handily for the slow workers (coincidence?) Given type of star that is most likely to form planetary system in first place, time is available to incubate life as it did on Earth.

Look at list of stars near Sun.

Barnard's *	6 L.Y.	May have planets
Lalande 21185	8.2 L.Y.	planets
ϵ Indi	11.3 L.Y.	Sunlike
τ Ceti	12.2 L.Y.	Sunlike

"Chances" for life about every 10 L.Y. through the Milky Way.

But if life is restricted to hippos on ϵ Indi, dinosaurs on τ Ceti, we can't detect.
What is probability that any nearby star has Technological Communicative Life?

This depends on factors we cannot seriously estimate in numerical terms:

) Whether or not the development of technology confers long-term evolutionary advantages on a life-form (we are much too recent as a technological society to assess this with any confidence). Can technological societies forestall population growth and/or self-destruction.

) Whether or not technological societies that become stable retain the capacity for and the interest in, communications.

All attempts to assess these probabilities based on human experience are like doing statistics with one sample — the estimates are biased by the fact that we who make them exist, & and of totally unknown uncertainty (variance), ∴ we have only one sample.

Optimists say that maybe some civilisations do stabilise and communicate. Then contact with these may assist others. Galactic cultural knowledge rescues infant societies from self-inflicted doom. So the "wise elders" actively promote interstellar signalling.

Pessimists note that the Australopithecine apes that evolved into Man used weapons as their first tools and are ∴ likely to be intrinsically destructive → doom for our society in few 100's of years → unlikely any other is in communicative phase right now

My own view is that we are too ignorant to make sensible assessments of these factors. Indeed one of the most effective ways of learning whether or not technological societies can survive would be to detect others and learn how widespread communication is through the Milky Way.

bigger the longer the lifetime of each.

$\#$ of communicating societies = $\#$ of planets with life $\times$ fraction that are "TC" now

So we might as well look rather than try to estimate social factors for which we have no basis.

Probability of contact is greatest if we consider contact with long-lived society (broader time window for contact to be possible).

So whether or not we should try depends mainly on how reasonable the search is technically over the distances involved.

Contact Consequences.

Biocosmology. Are we alone?
How prevalent is life in Universe?
Panspermia or separate creation?
Alternate biochemistries?
Galactic culture? How stable are societies?
Is there i/stellar travel, or just communication?
Does life exist at mercy of Universe, or is there any long-range control?

Hazards. Invasion — not by listening! We have already transmitted for ~ 50 years so too late to worry.
Subversion — again not unless we are dumb will be building "takeover computers".
Cultural Shock — could we tolerate being inferior, or hopelessly inadequate? Man the Supreme Being is not far behind in our culture.
Communication would be v. slow. Man would have plenty of time to adjust his thinking. Benefits seem to outweigh disadvantages.

Above all, adventure, quite deeply. This after all is ~~the~~ essence of Man's rise!

Worst possibility is that, as with dolphins, we simply won't understand!

Classes of signal

LEAKAGE

Our own main 'signal'
Best way to detect our civilisation from Mars, Jupiter, etc.
Pioneer 10 8-watt transmitter detected from Jupiter by Goldstone 210-foot. We could detect Kingston taxicab in Syrtis Major !

TV is major contributor - but cable TV coming in in Americas

Signal character: Highly monochromatic components
~~Synchronic slots across spectrum~~
Strong 24-hour cycle
Sinusoidal frequency modulation daily/yearly

Typical TV transmitter 20 kW
About 13 dB gain (restricted to about 6° elevations)
At 15° per hour Earth rotation, could be studied for about 20 min at a time.

Optimum band about 1 MHz around signal frequency

Assume our best receivers, i.e. about 20 K noise
about 1000-ft dish (Arecibo)
Could detect TV at 150 L.Y.
Probably a bit further if detected several at once.

Actually can't put best receivers at Arecibo, lose a factor of ten in sensitivity that way, so lose about 3 in distance.

BEACONS

Why ?
To facilitate acquisition phase for other races.
To transmit cultural history of dead civilisations (plenty of time for this as first Population I stars at least 9 billion years old). Note this might contain <u>cosmological</u> information.

<u>Directive</u> would mean they would have to choose recipients. For a given range this becomes ineffective becausem need large number of beacon beams to reach all stars. Directive beacons likely to be short-range, from similar stars.

Omnidirectional beacons make sense for long-range <u>acquisition</u>. If distant race wants to facilitate long-range acquisition then they would use omnidirectional beacons at 'uncryptic' frequencies.

Actual communication (2-way) might then be with directive systems after acquisition.

Uncryptic properties of beacons:

Continuous transmission
~~Circular polarisation (easiest to detect if any pol. used)~~
Modulated - FM would not jeopardise detection.

Biggest power easiest to handle at low frequencies because waveg:ides etc. largest there, but this is technology-dept.

Noise limits and choice of freq.

3 K isotropic background, residual radiation from Big Bang

Low radio frequencies, synchrotron radiation from Milky Way, weakest at poles but still stronger than residual radiation below about 600 MHz.

Atmosphere. Water vapour peaks at 22 GHz
Oxygen at 60 GHz

But these would not be important for advanced communications above planetary atmospheres. Do not impose technology-independent limits like the background radiations.

More important is quantum noise, must have many photons to transmit signal. In temperature terms, this becomes appreciable above 100 GHz.

Minimum noise background between 1 and 30 GHz.
Also corresponds loosely to window of maximum interstellar transparency.
optical dust-limited
radio plasma-limited

So 1 - 30 GHz is "optimum" window.

Contact between astronomically-oriented societies likely to be facilitated by choice of frequencies that are 1) astronomically interesting
2) biologically significant.

Assume that beacons would be uncryptic, i.e. at frequencies that are likely to be ~~[illegible]~~ spotlighted by those seeking contact.

H line (21 cm) suggested ∵ it's most common element
extensive natural line (astronomers study it)

But I think good case exists also for the water-vapour line at 22 GHz.