Abstract: We lack signs of extraterrestrial intelligence (ETI) despite decades of observation of the universe in the whole electromagnetic spectrum. Could evidence be buried in existing data? To recognize ETI, we first propose criteria for artificiality based on thermodynamics and living systems theory. Then we extrapolate civilizational development to both external and internal growth. Taken together, these two trends lead to an argument that some existing binary stars might actually be ETI. Since these hypothetical beings feed actively on stars, we call them “starivores”. We present an independent thermodynamical argument for their existence, with a metabolic interpretation of interacting binary stars. The jury is still out, but the hypothesis is empirically testable with existing astrophysical data.

In 1960, Freeman Dyson proposed to search extraterrestrial intelligence (ETI) by looking for infrared radiation emitted by an artificial biosphere covering a star (Dyson 1960). Unfortunately, despite some searches, the results are negative (Jugaku, Noguchi, and Nishimura 1995; Carrigan 2009). We thus lack proof or even indication of ETI, a fundamental gap in our knowledge of the universe. Here I show that building on and extending Dyson's method leads to a new extraterrestrial account of known interacting binary stars. The jury is still out, but the hypothesis is testable with existing empirical data.

The Dysonian SETI approach (Dyson 1966; Ćirković 2006; Bradbury, Ćirković, and Dvorsky 2011) opens new research agendas as it discards many implicit assumptions. Here in particular, I do not assume that putative ETIs necessarily use oxygen or carbon; that they live on a planet around a sun like-star or strive on temperatures or magnetic fields we know are suitable for life on Earth (see Sagan 1973, chap. 6; and Feinberg and Shapiro 1980 for debunking of such terrestrial chauvinisms). I also make no assumption regarding their communicative intent, nor that we should limit the search to our galaxy only.

Free of these assumptions, we can start to think systematically about life-as-we-don't-know it (Freitas Jr 1981). A common denominator to definitions of life is that it requires a metabolism, a manipulation of matter-energy by a force. But which force? Freitas systematically analyzed four possible metabolisms respectively based on the four fundamental physical forces: nuclear force (chromodynamics), electromagnetism, weak force, and gravitation.

Starting with such universal metabolic considerations, it follows that the substrate on which life or complex systems are based needs not to be unique. For
example, our computers' substrate has already changed five times since their invention, from electromechanical calculators to today's integrated circuits (Kurzweil 2005, chap. 3). In all cases, computers metabolize in a primitive way because they use energy to manipulate logical gates and dissipate heat. The lesson is that in astrobiology, as in computer engineering, what matters is not matter itself, but the ability to manipulate matter-energy and information.

How do we recognize ETI? To do so, we must establish criteria for artificiality. Let us further inquiry into thermodynamics and living systems theory, because these theories are universal and independent of a particular material substrate.

Criteria for Artificiality

The thermodynamical view of the universe can be quantified in order to describe the unfolding of 13.7 billion years of cosmic evolution (Chaisson 2001). Chaisson developed an empirical metric based on the rate of energy which flows through a system of a given mass (its unit is therefore erg.s$^{-1}$.g$^{-1}$). It uses only the fundamental concepts of energy, time and mass and successfully applies to describe the rise of complexity in physical, biological and cultural systems. Given such a billion-years applicability, we can reasonably hope that it would also apply to advanced extraterrestrials.

We can distinguish three kinds of more and more complex thermodynamical structures. First are equilibrium structures which are the subject-matter of classical thermodynamics, when applied to liquids or crystals. Then come dissipative structures which are in a nonequilibrium state and self-organize (Nicolis and Prigogine 1977). A famous example is the Belousov-Zhabotinsky chemical reaction, in which the concentration oscillates periodically, leading to the formation of non-trivial patterns. However, since the system remains closed to mass transfer, it finally reaches a state of equilibrium (Nicolis and Prigogine 1977, 340). The third kind of thermodynamical structures are living structures, which sustain a non trivial behavior and stay in nonequilibrium. They are best modelled as open systems, meaning that a flow of energy goes through them.

An additional thermodynamical criterion is the control of that energy flow, which is a necessary condition for the growth, maintenance, evolution and reproduction of complex systems (Aunger 2007). For example, a stone processes virtually no flow of matter-energy, and most scientists will agree that it is dead. On the opposite side, a wild forest fire grows and uses a lot of energy, but is uncontrolled. Living systems are in between these two extreme examples, controlling their energy flow.

Thermodynamical criteria are insufficient, since a refrigerator or a candle also do satisfy them. So, thermodynamical criteria are necessary but not sufficient to recognize extraterrestrials (Sagan 1975, 145). Living Systems Theory, a subdiscipline of systems theory, shows that all living beings display 19 critical subsystems (Miller 1978). The theory successfully applies at different scales, from cells to societies and constitutes a very useful guide to think universally about extraterrestrial life (see Harrison 1997 for an extensive application). The critical subsystems are divided in three broad categories. First, one subsystem, the reproducer, processes both matter-energy and information; second, nine subsystems process matter-energy and third, nine remaining subsystems process information.
Two Scales for Civilizational Development

Now that we have thermodynamical and living systems criteria, we need “candidate” ETIs to apply them to. A typical strategy to find advanced ETI is to extrapolate general trends of our own development. Although it is admittedly Earth-centric, we have to start somewhere, and we have just one option: life on Earth.

We distinguish two scales for civilizational development (Table 1).

<table>
<thead>
<tr>
<th>Kardashev Scale</th>
<th>Barrow Scale</th>
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<tbody>
<tr>
<td>KI – energy consumption at $\approx 4 \times 10^{19}$ erg.s$^{-1}$</td>
<td>BI – manipulates objects of its own scale $\approx 1$ m</td>
</tr>
<tr>
<td>KII – energy consumption at $\approx 4 \times 10^{33}$ erg.s$^{-1}$</td>
<td>BII – manipulates genes $\approx 10^{-7}$ m</td>
</tr>
<tr>
<td>KIII – energy consumption at $\approx 4 \times 10^{44}$ erg.s$^{-1}$</td>
<td>BIII – manipulates molecules $\approx 10^{-9}$ m</td>
</tr>
<tr>
<td>BIV – manipulates individual atoms $\approx 10^{-11}$ m</td>
<td>BIV – manipulates atomic nuclei $\approx 10^{-15}$ m</td>
</tr>
<tr>
<td>BV – manipulates atomic nuclei $\approx 10^{-15}$ m</td>
<td>BVI – manipulates elementary particles $\approx 10^{-18}$ m</td>
</tr>
<tr>
<td>BV – manipulates atomic nuclei $\approx 10^{-15}$ m</td>
<td>B$\Omega$ – manipulates space-time’s structure $\approx 10^{-35}$ m</td>
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Table 1: Energetic and inward civilizational development.

Kardashev’s (1964) types refer to energy consumption; Barrow’s (1998, 133) types refer to a civilization’s ability to manipulate smaller and smaller entities. Importantly these extrapolations make a minimum of assumptions because both energy and scale are universal physical concepts.

Extrapolating our exponential increase of energy consumption, Kardashev (1964) showed that this would lead our civilization to type KII in year $\approx 5164$ and to type KIII in $\approx 7764$. But we are still a KI civilization. What motivations could we have to evolve from type KI to type KII and harness the energy of the Sun? There are essentially two reasons. First, simply to meet our growing energy consumption needs. Indeed, the Sun is the obvious long-term resource to harness energy from, because it contains 99.8% of our solar system’s mass-energy. Exploiting the energy of a star is an explorative engineering field known as star lifting (Reeves 1985; Criswell 1985; Beech 2008). The second incentive is to engineer our Sun to avoid its red giant phase which will begin in $\approx 5$ billion years and will wipe out life on Earth. Various processes have been proposed for this purpose, resulting in an elimination of this red giant phase (Beech 2008).

Let us turn to the Barrow scale, which classifies civilizations by their ability to control smaller and smaller entities, as depicted in Table 1. This trend leads to major revolutions. Biotechnologies, nanotechnologies and information technologies are progressing at an accelerating pace and all stem from our abilities to control and manipulate small scale entities.

Barrow estimates that we are currently a type $\approx$BIV civilization which has just entered nanotechnology. We could estimate that chromodynamical lifeforms hypothesized by Freitas are type $\approx$BV and weak lifeforms $\approx$BVI. If we extrapolate the Barrow scale to its limits (type B$\Omega$), we come to a civilization able to manipulate space-time, or what Freitas called gravitational beings. However, because gravitation is such a weak field, a lot of mass and density must be present to obtain significant effects. Such lifeforms would thus ultimately be tied with black holes, and scientists have indeed speculated on various ways an advanced civilization could extract energy from black holes (Penrose 1969; Frautschi 1982).
Dense Interacting Binary Stars as Extraterrestrial Life Candidates

Let us apply the two scales to search for ETI. On the Kardashev scale, a type KII civilization would use the energy of its parent star. On the Barrow scale, small scales and high densities would attract intelligence, up to black hole organization (Vidal 2011). Combining both the Kardashev and the Barrow scale, could a civilization harness with great efficiency the energy of a star, to run its organization at black hole—or lower—density? Such configurations actually already exist! Indeed, many binary star systems composed of a dense body accreting gas from a companion star are known and studied, such as cataclysmic variables, X-ray binaries which include X-ray pulsars and microquasars.

Traditional astrophysics sees such white dwarfs (WDs), neutron stars (NSs) or black holes (BHs) as the stellar graveyard, because in most cases such dense bodies are theorized to be the remains of dead stars. However, some of these supposedly dead bodies display a perplexing variety of behavior more characteristic of the living world.

Let us visit the binary zoo with thermodynamical criteria in mind. Kopal (1955) classified binaries in three types: detached binaries, contact binaries, and semi-detached binaries. Broadly speaking, detached binaries are like two stones, they do not exchange matter-energy and do not influence each other. Contact binaries often evolve to a common envelope event, where stars exchange matter unstably and rapidly until the system reaches an equilibrium. The dynamics is similar to a wild forest fire. However, in semi-detached binaries, the energy flow exists, it is irregular but does not appear out of control. Their activity might hide a metabolism.

There are three main ways semi-detached binaries can interact (Eggleton 2006). They can interact via a conservative process, where the overall mass of the binary system is conserved. They are not good metabolic candidates because no entropy is expelled in a sink out of the system. In rapid non-conservative processes, mass is rapidly expelled out of the system, such as in type Ia supernovae, triggered when a WD accretes more matter than it can support, and explodes. They are also not promising ETI candidates because the duration is short and the end point is the total destruction of the system. The third category are the slow non-conservative processes, where mass is expelled out of the system, but in a slow way. They are promising because all the conditions of a metabolism are put together. There is an energy gradient between the star and the dense body, and such binaries display an irregular energy flow coming from their companion star. Furthermore, they dissipate entropy in the form of regular cataclysms (in WDs called cataclysmic variables) or jets (in NSs and BHs).

An objection is that not only living systems are out of equilibrium, but also dissipative self-organized systems such as chemical clocks. This is why we must ask if there is an energy flow control which allows the regulation of metabolic processes. If we turn to cataclysmic variables, microquasars and some X-ray binaries, their accretion pattern is varying, a fundamentally puzzling property challenging to explain (Mészáros 2010, 101). This could be interpreted as an active energy flow control.

To sum up, we now have enough concepts to define more precisely a putative ETI in a binary system: it is an extraterrestrial civilization using stellar energy (type KII on Kardashev's scale), in the configuration of a slow non-conservative transient accreting binary (thermodynamic criteria), with the dense primary (Barrow scale)
being either a WD, a NS or a BH. For convenience, I call such an hypothetical civilization *starivore*, defined simply as “a civilization that feeds actively on stars”.

An important strategy to understand living systems is to look at their waste products. If we apply this to WDs, we can study the novae ejectas which are expelled during novae. It is quite puzzling that the composition of novae ejecta displays heavy-elements abundance, ruling out the possibility that it is simply the accreted matter which is ejected (Gehrz et al. 1998). The alternative ETI interpretation is that the accreted material is used to perform work and waste is ejected as heavy elements.

How could work be performed under strong magnetic fields surrounding WDs? In fact, strong magnetic fields open up new ways of organizing matter, as the discovery of a third mechanism for chemical bonding in strong magnetic fields shows (Lange et al. 2012). This new *paramagnetic bond* adds to the *covalent bond* and the *ionic bond* and plays a role in the magnetized atmospheres of WDs.

Let us apply Chaisson's metric to binaries, to see how well they score. We can first calculate the theoretical maximum energy rate density that a binary could achieve. A crude estimate comes from the *Eddington limit* for luminosity (Frank, King, and Raine 2002, 3), \( \sim 1.3 \times 10^{38} \text{ (M/M}_\odot\text{)} \text{ erg.s}^{-1} \). We reach a theoretical maximum of free energy rate density of \( \sim 6.54 \times 10^{4} \text{ erg.s}^{-1}.\text{g}^{-1} \). Now, how do actual binary WDs, NSs and BHs score? Surprisingly, their luminosity can break this limit! They are amongst the few systems which display *super-Eddington* luminosity. Those values of energy rate densities are thus extremely high, since other astrophysical systems such as the Sun has a value \( \sim 2 \) and planets have \( \sim 10^{2} \). Higher values are otherwise known only for complex system such as a human body (\( \sim 2 \times 10^{4} \); (Chaisson 2001, 138)).

An objection against these suspiciously high values is that binaries display unstable states, indicative of destructiveness and not of constructive complexity. Indeed, supernovae, which are definitely destructive processes also do display high values (\( > > 10^{6} \); (Chaisson 2001, 157)). However, novae or jets are not supernovae, and associated binaries systems are not at all destroyed and generally not even disturbed by such events. The case of recurrent novae is particularly clear: even though they undergo impressive cataclysms, this happens recurrently.

This metabolic interpretation raises the objection that we did not take into account Miller's nine *informational* critical subsystems, despite that information processing is essential to the living. Could we search for information transmission from hypothetical starivores? This brings us to binary *pulsars*, which include the most puzzling ones, *millisecond pulsars* and *X-Ray pulsars*. Their artificiality has repeatedly been suspected (e.g. by Carl Sagan in Dyson et al. 1973; Edmondson and Stevens 2003), and it remains a key open question to assess it.
Conclusion

We showed with two independent lines of arguments that some binary stars are good ETI candidates. First, by extrapolating general energetic and scale-density trends of civilizational development; second, with a metabolic account of some existing binary stars in accretion. The starivore hypothesis invites us to look back at a chapter of high energy astrophysics with a fresh high energy astrobiological perspective. Contrary to most ETI speculations, this hypothesis is ready to be tested because binary astrophysics is a well established empirical science. I have further developed the hypothesis (Vidal 2013a, chap. 9) and set up a prize to be delivered for its corroboration or falsification (Vidal 2013b).

Percival Lowell elaborated a theory that canals on Mars were artificial. In 1895, the issue of natural or artificial canals was clearly formulated. Yet, during two decades, science was unable to confirm or infirm the theory (Dick 1996, 78). Let us hope that we will do better and take less time to assess the starivore hypothesis.

References


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