Can we get any traces from self-destructive civilizations?

Juan Manuel Espejo

Astrophysic context of life

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Introduction

Our understanding of the Universe is still pretty primitive when we take into account the timescales in the cosmological context and the large distances that we would have to travel to visit new places. For this reason it is very hard for us to determine in good detail how or when did the sparckles of life appear and how exactly it happened. Although we may infer many different aspects concerning life, we cannot assure that life doesn't manifest in ways that we don't really understand. Now, the evolution of life in other remote parts of the Universe might have already happened and they might have already destroyed themselves (as we can with our current technology). This could be an important and useful item to take into account for making a solution of the Fermi's Paradox.

Fermi's paradox states that it is paradogic that we haven't seen any other civilization in our galaxy because of its enormous size and the infinite possibilities of life to manifest in other stellar sytems. We should have already communicated with extraterestrial life but we haven't yet. Equally, SETI (search for extraterretrial intelligence) has been strongly influenced by this very known Paradox.

So, if we think abut the possibility that those civilizations have already come to an end, then the question is: Is there any possible way that intelligent civilizations that destroy themselves could present signatures that we could possibly observe?.

In order to answer this question we must remember the Drake equation and analyze the possible scenarios in which civilizations might be able to destroy themselves.

First, the famous Drake equation is a probabilistic argument created to make an educated estimate of the number of communicative extraterrestrial civilizations and it goes like this:

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

Where

R_* is the average rate of star formation in our galaxy.

f_p is the fraction of those stars that have planets.

n_e is the average number of planets that can potentially support life per star that has planets.

f_l is the fraction of planets that could support life that actually develop life at some point.

f_i is the fraction of planets with life that actually go on to develop intelligent life (civilizations).

f_c is the fraction of civilizations that develop a technology that releases detectable signs of their existence into space.

L is the length of time for which such civilizations release detectable signals into space.

Placing limits on the number of self-destroyed civilizations in the Milky Way has strong implications for the final three terms in Drake's Equation, and would allow us to identify which classes of solution to Fermi's Paradox fit with the evidence (or lack thereof). Solutions to the Paradox typically require the product of the final three terms of the Drake Equation, f_i, f_l, L, to be small. This phenomenon is sometimes referred to as "the Great Filter", as it removes potential or existing civilizations from our view. As there are three terms to modify, there are three broad classes of solution to Fermi's Paradox. The first is dubbed the "Rare Earth" class, and suggests that the fraction of planets with life that actually go on to develop intelligent life (f_i) very small. While there may be many planets inhabited by single-celled or multicellular life ($f_l \sim 1$) , very few generate metazoan organisms that go on to found technological civilizations to the point of evolution in which we stand.

The second class requires us to consider how civilizations might limit their detectability, where f_l and f_i may be large, but f_c is small. This could be due to agreements between existing civilizations to avoid the Earth or because the nature of reality requires there to be exactly one civilization in the Universe, i.e. the Universe is a sophisticated simulation. It is difficult to consider this scientifically since this class challenges epistemology. The third class demands that civilizations have short lifetimes (L is small). Usually referred to as the 'Catastrophist' class, this requires civilizations to be extinguished either through natural means or through self-destruction. The Catastrophist class implies that civilizations are fragile, either due to external threats from devastating phenomena such as asteroid impacts, supernovae or gamma ray bursts, or that civilizations contain inherent social or structural flaws that prevent them from sustaining themselves over long time periods. If the destruction of civilizations is inevitable, then this will fundamentally limit the number of communicating civilizations present at any time, with obvious consequences for SETI. Current SETI searches rely on detecting intentional or unintentional signals at a variety of wavelengths.

If we cannot rely on the current data from SETI to constrain the last three terms of the Drake Equation and conclusively solve Fermi's Paradox, what other data can we turn to? Recent developments which constrain the earlier terms of the Drake Equation, such as advances in the detection and characterisation of extrasolar planets or exoplanets are likely to be crucial. Our improving ability to characterise potentially habitable worlds may begin to yield clues about intelligent agents and their (possibly deleterious) effect on planetary properties. Taking a pessimistic view of the changes we have made to the Earth's surface, atmosphere and its local environment, it seems possible that we can analyze these changes in other extrasolar planets.

While it may be a morbid and depressing thought, looking for evidence of extraterrestrial civilizations that have undergone self-annihilation may be able to tell us much about the prevalence of intelligent life in the universe (f_i), as well as placing constraints on the length of time for which developed civilizations release detectable signals into space.

The scenarios that I read about and that I found more promising are:

i) Complete nuclear, mutually-assured destruction.

ii) A biological or chemical agent designed to kill either the human species, all animals, all eukaryotes, or all living things in the planet.

iii) A technological disaster such as the "grey goo" scenario.

iv) Pollution, that could be an excessive pollution of the star, planet or interplanetary environment

Other scenarios, such as an extinction level impact event, dangerous stellar activity or ecological collapse could occur without the intervention of an intelligent species, and any signatures produced in these events would not imply intelligent life so it is useless to treat or analyze them here.

Scenarios

i) Nuclear Annihilation

This is the first scenario we always think about since it is the closest we have been to destroy ourselves in the last decade, since the 80's we have enough nuclear power to create irreversible processes that could kill the human race on earth. Current estimates of nuclear weapons held around the world are of the order 6 million kilotonnes (kt) ($2.5 \times 10^{16} J$), with the large majority of this total being in Russian hands (they have always been interested in huge and very powerful weapons and they detonated the largest detonation ever recorded with the Zar bomb), we know that nuclear weapons produce a short, intense burst of gamma radiation with a characteristic double peak over several milliseconds. These gamma flashes could be detected using the same techniques as for the detection of gamma ray bursts (GRBs) from AGNs for example. In fact, the earliest detections of GRBs were initially thought to be nuclear weapons tests, due to their similarly short timescales and some similar spectral features, making cold war tensions even greater.

If a distant civilization went to extinction through the explotions if nuclear weapons, in principle we could be able to detect the gamma ray bursts that the event would produce, however, GRBs are distributed evenly across the entire sky, pointing to origins beyond the Solar System, and indeed beyond the Milky Way. GRBs constitute the most distant objects ever observed by humanity. For example, the GRB 120923A has a measured redshift of z=8.5 (cf Tanvir 2013). Given that the world's nuclear arsenal is equivalent to around $10^{19} J$ of energy, the resulting radiation from its combined detonation would be much fainter than a typical GRB. Also, the detonation must be very close to us because it is much less powerful than GRB produced in mergers of AGNs and it should be detected at the peak of the emission. However, the production of fallout from terrestrial size payloads, which persists for much longer timescales, may make itself visible in studies of extrasolar planet atmospheres.

Given that spacecraft and Earth based telescopes have detected (faint) nighttime airglow on Venus and Mars it may be possible to measure what would be considerably brighter airglow features in exoplanets, given that the order of magnitude increase in electron density caused by a nuclear war would generate an order of magnitude increase in airglow brightness. The brightest airglow feature in the visible spectrum on an Earth-like exoplanet would be the green oxygen line at 558 nm, which would be enhanced by global nuclear war to a photon flux of up to 1400 rayleighs. The thermal effects of nuclear explosions also affect atmospheric chemistry and so the disruption of an exoplanetary ozone layer presents another potential observational signature.

Atmospheric effects of nuclear warfare have been extensively modelled in climate simulations, the global consequences being known as "nuclear winter". Recent simulations have shown that even with reduced modern nuclear arsenals severe climate effects are felt for at least ten years after a global conflict, especially due to the long lifetime of aerosols lofted into the stratosphere They show that the atmospheric optical depth is increased several times for several years and that would be our best chance to determine if a nuclear war took place in an explanet.

Although this scenario is quite possible, there are more possible scenarios that we don't usually take into account but that in the long run could be our tools to determine the exitence of other civilizations in our galaxy.

ii) Biological Warfare

Virus can be very dangerous for a large population but could hardly kill all humankind in our planet, but it is still possible that somehow virus or bacteria could annihilate an intelligent civilization so we must study this scenario. The destruction cause by a virus would be self-limiting; once a population is reduced in size, transmission from host to host would become more difficult and the epidemic eventually ends. Artificially modified or created biological agents however, could potentially push a civilization to extinction.

The extinction of humans on earth due to engineered micro organisms, would cause a decay in the elementary elements via biomass decay that would go to the atmosphere and could be spectrally detected, but this process would be very fast and it wouldn't be easy to detect. But, if the virus kills very fast all the animals in the planet, the biosignature would last for about 30 years and it would be a lot easier to detect. The most promising biosignature gas for global bioterrorism is CH_4.

Spectroscopic data from exoplanets could evidence a strange abundance of CH_4 and that could be a trace of an unusual production that could be the result of a global epidemy that kills all large inhabitants of the planet.

iii) Destruction via "Grey goo"

The terrestrial biosphere offers many examples of naturally occurring nanoscale machines.

Following Phoenix and Drexler (2004) an author of one of the papers I read defines an engineered system that can duplicate itself exactly in a resource-limited environment as a self-replicator. These self-replicators, have the ability to replicate themselfs using the biosphere causing a chain effect.

The engineers of such machines have two broad choices as to what resources the selfreplicator might use: resources that are naturally occurring in the biosphere, and resources that are not. The ones that make the former choice run the risk of a "grey goo" scenario, where uncontrolled self-replication converts a large fraction of available biomass into self-replicators, collapsing the biosphere and destroying life on a world.

In Engines of Creation, Drexler (1986) notes: "Replicators can be more potent than nuclear weapons: to devastate Earth with bombs would require masses of exotic hardware and rare isotopes, but to destroy all life with replicators would require only a single speck made of ordinary elements. Replicators give nuclear war some company as a potential cause of extinction, giving a broader context to extinction as a moral concern."

Nanotechnology, if left to consume large quantities of biomass, will produce extremely dusty atmospheres and large amounts of surface "desert" which could yield detection via shadow-hiding during transit photometry observations. These signatures would remain on thousand year timescales, and potentially far longer depending on the rate that the nano-sand is delivered to the ocean floor.

iv) Pollution

Pollution of the host star

It is also possible that civilizations may wish to deposit waste material on their host star, especially if such waste is deemed hazardous. The byproducts of nuclear fission are certainly hazardous, and remain so on significantly long timescales some authors proposed terrestrial storage systems for high-level waste products are designed with a view to being secure for at least 10,000 years.

It could be possible that other civiliztaions deposit their waste material onto their host star contaminating it's atmosphere. If the outer convective layer of the star is not too deep, then it seems likely that this waste will remain near the stellar photosphere, and hence be detectable in stellar spectra. Shklovskii & Sagan (1966) went as far as suggesting that civilizations might "salt" their star by deliberately placing rare isotopes in the stellar photosphere to act as an interstellar marker for other civilizations to detect, this could be actually a good idea for civilizations to trace their existence in the vast Universe where the observations are very limited due to the large distances.

These signals that we could observe of a star contaminated by the civilization's waste do not distinguish between living and extinct civilisations. At best, we can consider the extreme case, where large amounts of artificial pollution begin to alter the star's equilibrium structure.

We don't really know how stellar pollution might affect life in the planet, however, if the effective temperature of the star changes as a result of the deepening surface convection zone, while the luminosity remains constant, the habitable zone boundaries of the system will move inward, and consequently planets that were previously habitable may become too cold to support life. Such an event would require drastic levels of pollution to achieve.

So, is stellar pollution a useful marker for exopocalypse? It seems to be the case that stellar pollution is an indicator of the presence of intelligence, but as has been mentioned, it does not clearly distinguish between living and extinct civilizations. Stars that have extremely large abundances of fission byproducts, along with planets near to, but beyond the outer edge of the local habitable zone, may be good candidates for sites of dead civilizations, but such evidence is hardly conclusive.

As every in science, it needs to be studied further and see how plausible it is to observe stellar atmospheres in search for extraterrestrial life.

Pollution of the host planet

We know that our indrustries and machineries contaminate our atmosphere in many ways, the main and most detectable compounds are CFCs (chlorofluorocarbonates) due to the industry. Actually, it has been demonstrated that the JWST could detect CFCs at ten times the Earth's levels in the atmospheres of Earthlike exoplanets. So if we think that civilizations in other stellar systems also aquire their energy from fosile oils, their emissions of many of these compounds would contaminate their atmosphere and it would be something we could actually observe with our spectroscopic analysis of them.

One of the advantages of this possible scenario of detencting life in other planets is that a CFC-polluted exoplanet could remain detectable for a substantially long time, giving us a bigger range in time of observations and thus making the possibilities of find life even larger.

So, strong signals of long-lived CFCs would be a good indicator of either a) an extinct industrial civilization, or b) a surviving industrial civilization that has ceased producing CFCs. but in any case, they could be a tracer that there is something in the planet that is producing this excess in the compounds that we are used to.

Pollution of the planetary orbital environs

Since humankind started conquering the space, we have been throwing our trash to orbit and leaving it there, it could seem that the ammount of debris we have left in the space is very low compared to the size of the near orbits but right now we have to be conscious that the ammount of debris has reached unexpected values and this problem must be considerate since it could cause accidents in the low orbits and could eventually bring a domino effect with the interaction and collisions produced by this large density of debris.

This possible collisional cascade that I just mentioned is now commonly referred to as Kessler syndrome. Kessler many some calculations concerning the trash we have left in space and his results showed that a first collisional cascade would occur in 2000. While the onset of Kessler syndrome by the year 2000 did not come to pass, it may still occur in the future. Although the ammount of debri that could harm significantly an intelligent civilization is very large, the effects would be possible to see from a further way observer like us. For example, large ammount of debri could account for a formation of large rings around the planet changing the intensity and properties of the transits of the planet.

We can say that detection of an artificial ring system around a habitable planet implies a civilization has undergone a Kessler syndrome event - whether such an event is catastrophic will rely on the density of debris, and the civilization's dependence on the orbital environment for sustaining itself. It could be argued that civilization might continue in the absence of satellite technology or general access to space, but the existence of the rings would still be measurable.

We know that planets can have rings naturally but the composition of an artifitial ring would be slightly different and we could use spectroscopic technieques to infer the nature of the rings.

Total planetary destruction

This is a very apocalyptic scenario and has to do with the destruction of the planet by advanced technologies that are able to do so. One possibility for this to happen is the hypothetical existence of something like the Dyson sphere. This sphere consists of a hypothetical sphere that surrounds the host star for obtaining its energy. In a solar system, in order to build a dyson sphere we would need to destroy Mercury and Vens to use their material, so we can think that an intellignet civilization that wants to build a Dyson sphere would need to destroy some of the surrounding material in order to use it for the contruction or we can also think that if a civilization is able to destroy a whole planet, they would do it anyway. The explisions would be a trace of inteligent civilizations and we could observe such blasts.

The Earth's binding energy is of order 10^{39} ergs. This is again several orders of magnitude fainter than a typical supernova or GRB of 10^{51} ergs, but is strong compared to the solar luminosity, so the Sun would require several days to radiate the same quantity of energy. This would likely produce a gamma ray signature even stronger than expected from the nuclear winter scenario described previously, and we may expect afterglows similar to those observed in other astrophysical explosions.

A big problem of this scenario is that it is only detectable in short timescales and we would have to be very like in order to observe it at the right time.

Conclusions

As we have seen, the observational signatures of self destroyed civilizations decay on a variety of timescales. Some decay so rapidly it is unlikely that we will observe them without a large amount of serendipitous measurements. But it is possible that other scenarios could destroy civilizations and they could be easily measurable for us, we just don't know about them yet. The following table organizes the possible death channels and gives us an overview of the timescales that each process would give us the chance to detect:

Death Channel	Detection Method	Active	Death	Detection timescale
Nuclear detonation	**Gamma ray detection, Transit spectroscopy**	**yes**	**yes**	**0-5 years**
Bioterrorism	**Transit spectroscopy**	**yes**	**yes**	**1-30 years**
Grey Goo	**Transit spectroscopy and photometry**	**no**	**yes**	**$>$1,000 years**
Stellar pollution	**Asteroseismology, stellar abundance studies**	**yes**	**yes**	**$>$100,000 years**
Planetary pollution	**Transit spectroscopy in the infrared**	**yes**	**yes**	**10-100,000 years**
Orbital Pollution	**Transit spectroscopy and photometry**	**yes**	**yes**	**$<$100,000 years**
Planetary destruction	**Debris Disk imaging in the infrared**	**yes**	**yes**	**$<$100,000 years**

The probability of detection depends sensitively on the means by which a civilization suffers annihilation. In most cases, the destruction of a technological civilization leaves atmospheric traces that persist for a short time, requiring observations to be relatively serendipitous.

In closing, it is clear that some observational signatures of self-destructive civilizations are currently amenable to astrophysical observations, but these will be challenging, and in some cases will require a degree of luck in observing at the correct time. However, these detection techniques are relatively cheap, as they dovetail neatly with current astronomical surveys. In time, the first evidence of extraterrestrial intelligence may come to us from the remains of less prudent civilizations that annihilated themselves. In doing so, such information will bring us not only knowledge, but wisdom.

We could think that it is not such a crazy idea to think that many civilizations have already died and that we might be going in the same direction. Although this is a very sad thought, we have seen through history that destruction and war is inherent to our nature and we are capable of taking really bad choices that could take us in the wrong direction of evolution.

I think that a universe so large and vast has infinite possibilities that in some future would be well explored; maybe one day civilizations will be able to communicate and interact. Right now we might be very primitive in the scales of the universe but the fact that we can argue and look for life in other places makes me think that we are part of the first steps in the quest for life in the Universe, and it is a privilege to be part of something so sublime and beautiful.

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