Exoplanets and SETI

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Abstract  The discovery of exoplanets has both focused and expanded the search for extraterrestrial intelligence. The consideration of Earth as an exoplanet, the knowledge of the orbital parameters of individual exoplanets, and our new understanding of the prevalence of exoplanets throughout the galaxy have all altered the search strategies of communication SETI efforts, by inspiring new “Schelling points” (i.e. optimal search strategies for beacons). Future efforts to characterize individual planets photometrically and spectroscopically, with imaging and via transit, will also allow for searches for a variety of technosignatures on their surfaces, in their atmospheres, and in orbit around them. In the near-term, searches for new planetary systems might even turn up free-floating megastructures.

Introduction

The discovery and characterization of exoplanets is central to astrobiology: exoplanets are the most natural locations to search for life elsewhere in the universe. One approach is to move toward the detection of biosignatures that might be produced extraterrestrial life; the search for extraterrestrial intelligence (SETI) focuses instead of technosignatures that might be produced by intelligent life.

Many proposed technosignatures of extraterrestrial civilizations in addition to electromagnetic communications might be observable today or in the
foreseeable future, including city lights, atmospheric pollutants, waste heat, and the transits of megastructures. The search for such technosignatures is often called artifact SETI (distinguished from communication SETI).

Indeed, these civilizations need not be active today to be detectable. Freeman and Lampton (1975) and Campbell (2006) proposed artifact SETI as a form of interstellar “archeology,” suggesting that we might find the remnants of extinct extraterrestrial civilizations, a theme extended by Carrigan (2012), and Stevens et al. (2016).

Exoplanets as Schelling Points in Communication SETI

Two of the many dimensions of the vast parameter space of communication SETI (e.g. Tarter 2001) are when to observe (or transmit to) a given target, and which directions to target at a given moment. If one assumes that the search for and transmission of of deliberate signals (“beacons,” Dixon 1973) is a mutual endeavor, then one can turn to game theory’s analysis of the problem of a cooperative game in which the players cannot communicate.

Schelling (1960) described focal points (better called Schelling points in astronomy to avoid ambiguity) as mutually obvious locations in the strategy space of such a game. His examples involved finding a person in a city who is also looking for you, and radio SETI, citing Cocconi and Morrison (1959). Guessing the times and places to meet in the city, and guessing the frequencies to tune to in radio SETI, are superior strategies to random ones. In the city, this might include the locations of famous landmarks and times that bells chime or other coordinated actions occur; in radio SETI this might mean astrophysically significant frequencies and their multiples. Makovetskii (1980) called this a “mutual strategy of search” for “synchrosignals” (Makovetskii 1977), and Filippova et al. (1991) described this concept as a “convergent strategy of mutual searches” for SETI (both apparently unaware of Schelling’s prior art).

Where to Observe

Exoplanets form a natural Schelling point, and since communication SETI efforts typically spend more effort on targets where life is more likely to be found, they make natural communication SETI targets. Since the beginning of the field, communication efforts have focused on Sun-like stars likely to host habitable planets (some recent examples of such target lists include Henry et al. 1995; Turnbull and Tarter 2003a,b).

The prospect of alien civilizations detecting Solar System planets as exoplanets inspired similar thoughts. Filippova and Strelnitskij (1988) called
the ecliptic an “attractor for SETI” because Earth would appear to transit the Sun from stars there. Corbet (2003) argued that all stars at opposition (i.e. those seeing Earth at inferior conjunction, not just those seeing Earth transit) should be searched for this reason.

As Bracewell and MacPhie (1979) predicted, the discovery of individual exoplanets, especially rocky planets and those in the Habitable Zones of their host stars (Kasting et al. 1993), has naturally focused efforts on them and their orbits (Siemion et al. 2013; Panov et al. 2014; Harp et al. 2016).

That said, the discovery of many exoplanets has also shown that the occurrence rates of rocky exoplanets in the Habitable Zones of stars is so high (of order 10%, and likely higher Traub 2012; Petigura et al. 2013; Dressing and Charbonneau 2015) that no stars should be neglected simply because they have not had any of their habitable planets discovered yet. This is why many surveys have returned to the original strategy of surveying stars independent of their known planet status (Maire et al. 2016; Isaacson et al. 2017).

When to Observe

As suggestion for a temporal Schelling point, Pace and Walker (1975) suggested observing binary stars during periastron and apastron. Makovetskii (1977) suggested sending and listening for signals coincident with other predictable astronomical phenomena, targeting those and opposites part of the sky. This transmission strategy would mean that even astronomers observing these phenomena for non-SETI purposes might detect the signal.

Again, considerations of the Solar System objects as exoplanets has sharpened the discussion. Singer (1982) suggested using the times of maximum displacement of the Sun by Jupiter as Schelling points; Filippova et al. (1991), and later Shostak (2004) suggested that we search stars along the ecliptic during the time Earth would appear to transit from the transmitter’s perspective, although this strategy requires either the transmitter or the receiver to make adjustments for light travel time, which requires precise knowledge of the distance between them.

The actual discovery of transiting exoplanets has allowed for an even more focused approach: searching for signals during the time the exoplanet transits. Kipping and Teachey (2016) argued “the time of transit provides a natural communication window, analogous to water hole in radio SETI (Oliver 1979),” (i.e. a Schelling point). This strategy has the advantage that distances to the targets need not be known (the light travel time is the same for the signal and the light of the transit). By an extension analogous to that of Corbet (2003), one might search any planet during its inferior conjunction with its star.
Technosignatures on Exoplanets and the Host Stars

If alien civilizations are not broadcasting beacons we are meant to find, then the Schelling point concept is irrelevant, and the questions of where and when to look revolve around different questions. For communication SETI, this means when and where are we most likely to intercept leaked emission. For instance, Siemion et al. (2013) proposed eavesdropping on planet-planet communications which is best performed when two inhabited planets in an edge-on multiplanet system are in conjunction and transmissions from the farther to the nearer planet will be inadvertently directed at Earth. Guillochon and Loeb (2015) proposed looking for leaked energy from propulsion systems at the same time for that same reason.

On the artifact SETI side, although the direct imaging of large structures on exoplanetary surfaces would require angular resolutions too far in the future for even this work to consider, other options exist (Kreidberg and Loeb 2016; Cowan and Fujii 2017). Campbell (2006) and later Schneider et al. (2010) proposed that the direct imaging of exoplanets presents special opportunities for the detection of technosignatures. Surface maps can be constructed using a planet’s rotationally modulated brightness (Kawahara and Fujii 2010). This is even true when they are not directly imaged, both in photometry (Knutson et al. 2007), and from their secondary eclipse light curves (Majeau et al. 2012; de Wit et al. 2012).

**Waste Heat** A mid-infrared map with sufficiently high sensitivity might allow one to conduct a waste heat search for civilizations (Dyson 1960; Cartrigan 2009; Wright et al. 2014a) by looking for industrial heat signatures on the planetary surface. For instance, Kuhn and Berdyugina (2015) suggested that a 70m telescope might be sufficient to detect the rotationally modulated localized output of industry on an Earth-like planet for a civilization with \( \sim 25 \) times the energy supply of humanity (which is equal to about 1% of light the planet intercepts from its star).

**Artificial Illumination** Schneider et al. (2010) suggested that artificial light sources might be detectable on the night sides of planets, and Loeb and Turner (2012) pointed out that proposed versions of space telescopes might be able to detect such “city lights” via direct imaging if they are a few times more powerful than those of Earth.

Kipping and Teachey (2016) recommend searching for laser emission at the time of transit, especially in the form of anomalous transit light curves or transit spectra. They suggest that a civilization might use such lasers to attract attention when we are studying their planet’s transit, or might use it to “cloak” their planet’s transit light curve or spectrum biosignatures.

**Spectroscopic Detection of Pollution** Exoplanetary atmospheres are amenable to spectroscopy in several ways, including in thermal emission and via reflection/absorption of starlight, and via transit spectroscopy. These
techniques can all probe different wavelengths and atmospheric depths, and so potentially probe a variety of atmospheric technosignatures. Schneider et al. (2010) suggested that technosignatures might be present in the atmosphere in the form of unnatural chemical substances, perhaps due to pollution, such as our chlorofluorocarbons (CFCs) or photovoltaic arrays (Lingam and Loeb 2017). Lin et al. (2014) calculated that over 1 day of integration with the James Webb Space Telescope might be able to detect CFCs at only 10 times their current concentrations on Earth. Stevens et al. (2016) also presents several scenarios that might only be just detectable and recognizable if we were to happen to catch a cataclysm like those we fear for Earth at the moment it happened, cosmically speaking. For instance, they argue that the signatures of global nuclear war, including gamma rays, the chemical effects of radioisotopes and the heat of nuclear weapons, and the following “nuclear winter” might all be detectable with sufficient precision of imaging and spectroscopy across the EM spectrum.

More likely, perhaps, than alien civilizations producing the same sorts of pollution that humans do or might create in the near future, would be the creation of clearly artificial chemicals of utilities that are unclear to us. An unrecognizable spectral signature might pique interest for further study, as astronomers travel down the long road of exclusion of natural causes (Wright et al. 2014b).

Not only the planet might host pollution. Despite the folly inherent in suggestions to launch humanity’s waste into space, advanced civilizations might use their star as a dumping ground for dangerous or otherwise unwanted substances. Whitmire and Wright (1980) suggest it might be done as a way to dispose of fissile waste, and Stevens et al. (2016) suggests such dumping might even result in a detectable environmental catastrophe. On the other hand, Shklovskii and Sagan (1966) note independent suggestions by Drake and Shklovskii that such pollution might be created deliberately as a “beacon.”

Regardless of the reason for its presence, in most stars such pollution would be atomized and ionized by the star’s envelope, and so would be only detectable via abundance anomalies, especially for elements or isotopes that are inherently rare in stars. Whitmire and Wright (1980) suggest praseodymium as a good tracer of artificial nuclear reactions. Przybylski’s Star (Przybyski 1961; Cowley et al. 2000) which shows evidence of high concentrations of numerous lanthanides and short-lived actinides in its atmosphere, is occasionally mentioned as a SETI candidate under this category (although never, that I can find, in the refereed literature.)

1 Roughly pronounced (p)shi-BILL-skee, with a weak initial "p" as in the interjection "pshaw"
Dyson (1960) suggested that advanced alien civilizations might intercept large amounts of starlight to power themselves, and be detectable by their waste heat in the mid-infrared. Dyson had in mind that the total infrared flux from the star would be anomalously large, but future direct imaging efforts may have the sensitivity to detect planet-sized starlight-blocking structures in reflected light or thermal radiation directly.

Arnold (2005) applied this reasoning to the Kepler space observatory, noting that its photometric precision was sufficient to distinguish planets from planet-sized objects with non-circular aspect ratios. Arnold (2005) further noted that such structures might serve not just as power collectors but as highly efficient beacons (efficient in terms of the ergs per bits required to transmit information, since they passively block EM radiation being emitted anyway by the star).

Other artifacts that might be discovered include large satellites of inhabited planets (Korpela et al. 2015), very large shields (Forgan 2013), or rings from a cataclysm (Stevens et al. 2016) such as a runaway collisional cascade of artificial satellites (“Kessler syndrome” Kessler and Cour-Palais 1978) or even total planetary destruction.

Wright et al. (2016) enumerated ten ways that planet-sized artificial structures (“megastructures”) might be distinguished in a transiting planet survey from planets including anomalous light curve shapes, colors, transit timings, and follow-up signals. They also noted natural confounders in each category; indeed each of their ten signatures is already being sought (and found) as a way to measure planetary masses (e.g. via transit timing variations), planetary clouds, exomoons, exorings, stellar and planetary oblateness, stellar limb and gravity darkening, atmospheric escape, starspots, orbital eccentricity, and circumstellar disks.

The list of the confounders for these ten signatures are actually a good list of the most exciting topics of exoplanetary research in the future. Artifact SETI can thus “piggyback” on work likely to happen in the future, anyway, as natural anomalies are discovered in the course of exoplanetary science. Indeed, the pulsar planets (Wolszczan and Frail 1992) show that we can expect to find planets, and thus, potentially, life (indigenous or not), around all types of stars. The search for megastructures should thus include pulsars (Osmanov 2016), X-ray binaries (Imara and Di Stefano 2017), and other systems.

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