210. SETI, Game Theory, and Gaia

I LOOKED AT SOME aspects of SETI in essay 55, including Gaia's contribution to searching for an optical counterpart to the 'Wow!' radio signal of 15 August 1977. And I described two other examples of recently discovered celestial phenomena which probably have a purely physical explanation, but which have aroused interest as being possible alien techno-signatures, and where Gaia is contributing to a more complete picture: the 'interstellar travellers' (viz. Oumuamua and Borisov, essay 25), and the curious 'Boyajian-type' stars.

Here, I will look at a class of SETI search strategies which benefit substantially from the availability of high-accuracy astrometry.

LET ME FIRST recall some background. The search for extra-terrestrial intelligence, SETI, is motivated by the belief that intelligent life is likely to emerge under conditions similar to those on Earth. There is a substantial literature, amongst which are considerations by Cocconi & Morrison (1959), Drake (1961), von Hoerner (1961), von Hoerner (1973), Townes (1997), Leigh & Horowitz (1997), Bhathal (2000), Tarter (2001a), Drake (2008), Ćirković (2013), and Cabrol (2016).

Loosely connected but not implicit in such searches are various unproven and somewhat inconsistent postulates, amongst them the 'anthropic principle', which suggests that no assertion can be made about the probability of intelligent life based on a sample set of one (e.g. Barrow & Tipler, 1988); the 'mediocrity principle' which, given the existence of life on Earth, asserts that life typically exists on Earth-like planets throughout the Universe (e.g. von Hoerner, 1961); and the 'fine-tuning hypothesis', which asserts that the natural conditions for intelligent life elsewhere are implausibly rare.

SETI is generally not perceived as an activity which merits public funding, and is (with some exceptions) an aside to today's mainstream research. Nonetheless, many searches at radio, microwave, and optical wavelengths have been undertaken over the past 30–40 years. All have been unsuccessful, with some false alarms (essay 55), and I will not describe them further here.

THE CHALLENGES in searching for extraterrestrial intelligence are compounded by the multiple dimensions of potential search space. Accordingly, searches for (intentional or accidental) signals clearly benefit from insights as to what wavelengths and types of signal to search for, along with where (and when) to look (e.g., Tarter, 2001a; Tarter, 2001b; Shostak, 2011a; Shostak, 2011b; Fridman, 2011). And when transmitting a signal over large distances, it may well be more efficient to send a brief beamed signal than one which is continuous and omnidirectional, but this again requires that the receiver can figure out where and when to look.

The problem can be simplified if the signal transmission and reception are considered of mutual interest to both parties. In that case, appeal can be made to 'game theory' to formulate a cooperation in which, although the players cannot communicate, they can still establish strategies which are superior to purely random searches.

THE BACKGROUND has been nicely laid out by Wright (2018), and rests on concepts detailed in the book 'The Strategy of Conflict' by American economist Thomas Schelling (1960). The idea is to establish 'focal points' (aka 'Schelling points' or 'beacons') as preferred locations in space or time. Schelling's examples involved two people trying to find each other in a city (e.g. by considering prominent landmarks, or church bells), and the problem of choosing search frequencies for SETI.

Frequency choices range from the neutral hydrogen line at 1420 MHz (Cocconi & Morrison, 1959), to recent suggestions of the Planck energy multiplied by integer powers of the fine structure constant (Wright, 2020).

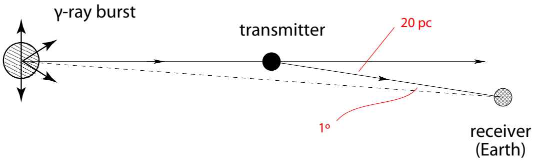
The use of astronomical beacons as *temporal* markers has been considered by a number of authors, invoking synchronisation with supernovae (in particular SN 1987A) and novae (e.g. Dixon, 1973; Tang, 1976, 1981; McLaughlin, 1977; Makovetskii, 1977, 1980; Filippova et al., 1991; Lemarchand, 1994; Seto, 2021), binary stars (Pace & Walker, 1975; Pace, 1979), γ-ray bursts (Corbet, 1999; 2003), neutron star mergers (Nishino & Seto, 2018), and even Sgr A* at the Galactic centre (Seto, 2024).

The idea underpinning these positionally-optimised search strategies is that a transmitting civilisation would transmit a signal at the moment that they register some chosen astronomical outburst. Then *their* transmission will be received on Earth with a delay (subsequent to the registration of the same astronomical event outburst on Earth) dictated by the path-length difference between the two routes (see figure below).

In the example given by Makovetskii (1977), using the outburst of Nova Cygni 1975, and a nova–Earth distance of 1600 pc (their 5200 light-years), the typical (pre-Hipparcos) star distance uncertainties at the time led to signal registration *uncertainties* on Earth, for 20 candidate transmitting stars, of the order of 10–100 d.

The accuracy of the predicted delay, i.e. the duration of the required search window, clearly improves with better positional accuracies of event and transmitter. The availability of the Hipparcos astrometry in 1997 generated renewed interest in this possibility.

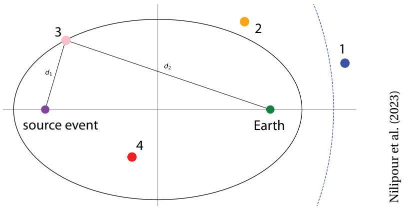
With his suggestion that γ-ray bursts provide excellent natural 'synchronisers' because of their luminosity, occurrence rate, isotropic distribution, large distance, and short duration, Corbet (1999) considered a transmitting civilisation propagating an 'announcement signal' downstream (i.e., $\sim 180^\circ$ away from the burst) immediately on receiving the burst signal. The searching civilisation (Earth) then monitors (angularly proximate) upstream targets star for a synchronised emitted signal at the time lag set by the additional path length.



Corbet (1999) estimated that a planet-hosting star at 20 pc from Earth, and at an angle of 1° from the direction of a burst event seen from Earth, will transmit an event which would be detected on Earth 3.63 d later, and with an arrival time that can be predicted to ±1.8 h. Even 14 years before its launch, he pointed out that the timing uncertainty would drop to just 60 s in the case of 10 μas Gaia-level parallaxes. For a number of his hypothesised transmitting stars, the errors on these time delays remain modest, below 1 day, for offset angles up to 5°.

While there have been no definite SETI-type signals detected to date, an optimist might hypothesise that the few detections of non-repeating signals, such as the 'Wow!' event, which I considered in essay 55, could conceivably be genuine extraterrestrial signals that are transient simply because the transmission was intermittent… perhaps along these sorts of lines.

A generalisation of this approach, introducing the concept of a 'SETI ellipsoid', had already been presented by Lemarchand (1994). Incidentally, it follows the same geometry adopted in the study of light echos around supernovae (Chevalier & Emmering, 1988).



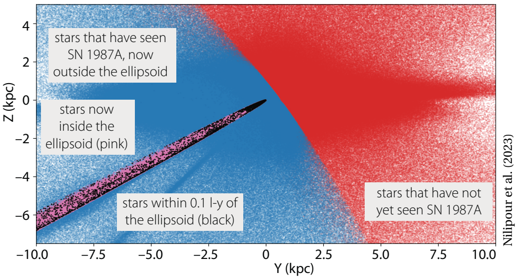
Nilipour et al. (2023)

The foci of the ellipsoid (which expands with time) are the source event, and Earth. All stars then fall into four groups: (1) those that have not yet observed the event; (2) those that have observed it, but any transmitted signal has not yet reached Earth; (3) those, on the ellipsoid, whose possible signal would now be arriving at Earth; (4) those where a signal would have arrived in the past.

Davenport et al. (2022), who explain this more carefully through the geometric properties of the ellipse, used the EDR3 Gaia Catalogue of Nearby Stars to select targets on the SN 1987A 'SETI ellipsoid' (as well ellipsoids defined by 278 novae). Less than 8% of stars within the 100 pc sample are inside the ellipsoid, such that the majority are still viable targets for monitoring. Some 700 stars per year within 100 pc will intersect the ellipsoid.

Cabrales et al. (2024) identified 32 suitable SN 1987A 'SETI ellipsoid' targets in the TESS continuous viewing zone. Their TESS light curves showed no anomalous signatures during the ellipsoid crossings.

Nilipour et al. (2023) used four historical supernovae, including SN 1987A, and 10 million stars from the Gaia DR3-based variable star catalogue. Less than 0.01% of stars in the sample have ellipsoid crossing times within the range of the Gaia DR3 observations. They used these to search for 'technosignatures' as modulations in the variability parameters by splitting the stellar light curve at the crossing time.



Nilipour et al. (2023)

Other searches using Gaia data include consideration of the 'Earth's microlensing zone' from which Earth's photometric microlensing is most readily observable (Suphapolthaworn et al., 2022), and identifying targets for METI-like messaging (Seto & Kashiyama, 2020).