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EDITORIAL

The prospect of von neumann probes and the implications for the sagan-tipler debate

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In the early 1980s, Carl Sagan and Frank Tipler published a series of articles in the pages of the Quarterly Journal of the Royal Astronomical Society on ETI that became a *cause celebre* at the time. Whilst reading for an MSc in Astronomy at the University of Sussex in the early 1990s, I expressed my interest in SETI as a staunch Saganite (influenced not only by the phenomenal *Cosmos* TV series, recently re-vamped by Neil de Grasse Tyson, but also by Sagan's preceding Royal Institution Christmas lecture series) to Professor John Barrow who introduced me to the relevant chapter in the book *The Anthropic Cosmological Principle* that he co-authored with Frank Tipler (I still recommend the entire book for its visionary scope). I immediately went to source material and was struck by the von Neumann or self-replicating probe concept under discussion (I shall use the latter term to avoid conflation with von Neumann machine which has a well-established meaning in computer engineering). This was my road to Damascus in converting me from ETI believer to skeptic (but by the power of scientific argument rather than any epiphany). Thence, I decided to pursue a PhD in space engineering specialising in space robotics (though my research project was rather more mundane than self-replicating probes). Yet, despite its foundational importance, the Sagan-Tipler debate is almost forgotten today despite the fact that it exposes the root-and-branch of the SETI venture. However, every now and then, there is still the occasional paper on self-replicating probes but they appear to be sidestream to the SETI programme. This special issue seeks to re-focus the self-replicating probe back into the SETI mainstream where it belongs.

There are four papers in this special issue. Dobler's (2022) paper provides the ideal contextual discussion of the Fermi paradox that extant ETI are not here now. He suggests that any optimistic interpretation must accept that there must be a low probability of contact and that this state of affairs shall continue. He suggests that, although no one explanation can account for the Fermi paradox, perhaps a suite of explanations applicable to different categories of ETI are sufficient to cover the universality of the problem. And this will remain so. This is reminiscent of the "wedges" approach to combatting climate change (Pacala & Solow 2004). It does require that the explanatory wedges, even if they shift their weightings over time due to dynamic factors, must retain their universal coverage of non-contact. Nevertheless, from an instrumental viewpoint, this differs not from the assertion that ETI do not exist as Dobler (2022) points out. Only stable factors such as implausibility of interstellar travel are universal enough to account for the existence of ETI with the persistent lack of evidence.

This dovetails neatly into Matloff's (2022) paper who addresses issues associated with the self-replicating probes including propulsion for interstellar flight. He analyses several plausible options of increasingly technological sophistication. The use of gravity assists, be they unpowered or powered, is well-established but such methods yield extremely long interstellar transmit times $\sim 10^3$-10^4 y/ly. Such probes would almost certainly be overtaken by more advanced probes within the next century. Various forms of nuclear propulsion were considered to improve performance and reduce flight times to ~1000 y/ly. Propellantless sails were also considered to offer similar performance.

Antimatter propulsion was deemed beyond our current technological capabilities. Even at low speeds, a significant fraction of the Galaxy is explored within 18 million years.

While Matloff (2022) considers several motives for self-replicating probes, Ellery (2022a) suggests that self-replicating machines (and probes) are an inevitable economic development in offering a low capital cost approach to any venture by virtue of their exponential productivity – Galactic colonization in 24 generations over ~1 million years or so at the cost of only one or two probes. Each self-replicating probe at its target destination would manufacture a maximum of 48 offspring over this period. Furthermore, since we are currently developing self-replication technology on Earth, application of the Copernican principle implies that any extant ETI must be assumed to have done so too.

While Matloff (2022) considers a range of locations for lurking self-replicating probes, Ellery (2022a) suggests that technosignatures of industrial activity might be found amongst asteroids. He examines in detail how a self-replicating probe might be manufactured by exploiting 3D printing technology in conjunction with methods being developed for in-situ resource utilisation for asteroids subject to severe closure conditions. He highlights electric motors and vacuum tubes as key technological levers to be extracted from asteroidal resources with which to construct robotic machines of production. He delves into chemical processing of asteroidal resources to extract specific functional materials to identify potential residues that might constitute technosignatures on our own asteroids but notes that self-replication closure enforces an efficient industrial ecology employing extensive recycling with minimal waste. Nevertheless, extensive deposits of clays on asteroids would constitute a readily identifiable technosignature. Ellery (2022a) then considers how the self-replication scheme could construct an interstellar propulsion system. The self-replicating probe must be robust enough to survive its flight to the nearest star – on average 5 light years distant if we assume our own solar neighbourhood stellar density. If we can muster 0.1c interstellar transit speeds - consistent with the Daedalus starship (Bond et al 1978) - the flight duration is 50 years rather 100s-1000s of years. Focussing on beamed propulsion methods using large area sails, Ellery (2022a) considers that the scale of interstellar propulsion requires self-replication of modular units to achieve such enormous scales. Free electron lasers are high-power vacuum tube technologies that can be focused by a large area Fresnel zone lens to propel a lightsail augmented by electric and magnetic sailing. All material requirements are consistent with the industrial ecology. Of course, there is no evidence of such giant structures in our solar system but a modular Fresnel lens and a free electron laser array would most likely disperse over time once they had achieved their goals.

Matloff (2022) mentions that the issue of interstellar flight longevity subject to hostile conditions including computer memory stability being unresolved but some of these issues are addressed elsewhere in Ellery & Eiben (2016). A more common concern is the grey goo scenario – an argument used by Sagan against the self-replicating machine. Ellery (2022b) addresses this to prevent self-replicating probes from running amok. He adopts a biomimetic approach to control self-replication capacity by imposing a Hayflick limit enabled by a telomeric counter. The mechanism of biological counting is considered in detail and how it is sometimes circumvented in the case of cancers. A direct electromechanical analogue of the telomere is suggested to ensure degradation of computer memory once the Hayflick limit has been achieved supplemented with a viral routine to corrupt neural network production. Nevertheless, there must be multiple layers of protection against runaway replication that have yet to be explored.

The self-replicating probe concept is being fleshed out from a physically plausible entity into an engineering system with immediate practical benefits for the rapid industrialisation of the Moon. The SETI community should no longer ignore the self-replicating probe concept but embrace it as a mainstream approach to SETI to explore its nuances. Contrary to perception, the self-replicating probe concept does not undermine the SETI programme - it *de facto* requires it in a Popperian sense. It also allows us to explore wider notions of life beyond biological life on Earth (Ellery 2018). Finally, broadening of technosignatures beyond artificial radio transmissions is laudible as it imposes fewer assumptions and a wider net for the search for evidence. The self-replicating probe concept has much to offer the SETI community and should be brought in from the cold.

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