UTILIZING PULSARS FOR IMPLICIT COORDINATION OF THE SIGNALING TIME-BASE OF INTERSTELLAR BEACONS. I. S. Morrison[1], G. R. Harp[2] and S. Oslowski[1], [1]Centre for Astrophysics and Supercomputing, Swinburne University of Technology, John Street, Hawthorn, Victoria 3122 Australia, imorrison@swin.edu.au, [2]SETI Institute.

Overall Goal(s) and Objective(s): Discovering an interstellar beacon signal is a multi-dimensional search problem, particularly for a wideband message-bearing signal modulated in a way we cannot guess. The search problem can be significantly eased if the extra-terrestrial beacon builder wishes to make their signal more easily discoverable and chooses key parameters of their signaling method that are deducible by their target recipients. In this white paper we specifically suggest that a beacon builder could choose a signaling time-base that is the period of a pulsar visible to both the transmitting and receiving civilizations. Constraining this parameter in the search leads to a massive reduction in the computational complexity of search algorithms for wide bandwidth signals, which otherwise are significantly more computationally demanding than conventional SETI searches for narrow bandwidth (<100 Hz) signals. This motivates the beacon builder to use wider bandwidth signals and, for SETI, opens up the possibility of real-time, high-sensitivity searches for wide-bandwidth interstellar sources.

Introduction: For 50 years since SETI began [1] it has been dominated by a search for engineered signals in the electromagnetic spectrum (mostly radio and optical). Searches in the radio frequency range face several technical challenges including the effects of dispersion in the interstellar medium (ISM), which can distort a moderately wideband (e.g. information-bearing) signal. Most radio SETI searches to date limit themselves to a small subclass of narrowband signals, which are minimally affected by the ISM, but cannot transmit substantial data in a human lifespan. This choice is somewhat counterintuitive, since one might expect ET to send an information-bearing hence wideband signal, either to communicate with us or with another civilization across interstellar distances. This paper describes a new concept that can dramatically simplify discovery of intentionally transmitted wideband interstellar signals with radio (or optical) telescopes, and thereby help to extend SETI searches into the domain of information-bearing signals.

Two of the authors have previously developed methods, summarized in [7], to effectively detect wideband signals in a SETI search. But detecting wideband signals of unknown form still poses serious challenges. In addition to not knowing where spatially and spectrally to look for such signals, we do not know what form of modulation has been employed, or any of the many parameters defining that modulation. Regardless of the method used, it is unavoidable that the many unknowns lead to a multi-dimensional search problem of high computational complexity. Algorithms that can make a detection in this scenario ("blind detectors") do exist and new approaches are in development [7]. There is a fundamental trade-off between detector specificity (how "blind" the algorithm is), detection sensitivity, and computational complexity. For the most sensitive detectors (assumed to be needed for SETI), the computational demands are generally much too high to enable real-time detection of wideband signals.

We note that an extraterrestrial beacon builder wishing to make it easier for its intended recipient to discover or lock-on to their signal can make specific choices for certain signaling parameters that they believe may be deduced by the recipients. The idea of a "magic frequency" (such as the H1 line) has been a mainstay of narrowband SETI thinking since its earliest days, motivated by a lack of resources to search over all frequencies. Nowadays, it is possible to search over a large range of frequencies at once, so the interest in magic frequencies has attenuated in the SETI community. But the resource issue has re-surfaced with the increased interest in wideband signal types where the carrier frequency is just one of many unknowns.

But what if we were able to reduce the dimensionality of the search problem by more tightly constraining some of the unknowns? This principle is termed "implicit coordination", and is discussed at length in [4] and [7]. It is possible to place credible constraints on the likely frequency band for interstellar beacons based on astrophysical limits and efficiency arguments [7]. But one important parameter that remains open-ended is the time-base of the modulation process used to embed information in the signal. We may be able to place some upper bounds on this, based on coherence bandwidth arguments for communications through the ISM [5], but we have no basis for setting any lower limit. As a result, searches need to be sensitive to many orders of magnitude in time-base rate, and with a fine resolution – resulting in a huge computational demand. For example, the SWAC algorithm [7] uses a trial-and-error approach in which a series of different assumptions are made for the signaling time-base. A trial of 10^6 or more different time-base values may be called for to achieve full coverage of the signal bandwidth being processed. Any reduction in the number of time-bases to consider will directly translate to a corresponding reduction in computational load.

Method: This white paper suggests that a highly effective means of coordinating a time-base value for interstellar beacons would be to choose this to be equal to the period of a pulsar that is visible to both the transmitting and receiving civilizations. Pulsars have very stable periods ranging from milliseconds to tens of seconds – a range consistent with practical beacon signaling rates.

This idea has similarities to one of the concepts mentioned by Bill St. Arnaud in his recent blog article concerning replicating and self-amplifying electromagnetic signals [8]. He talks of exploiting the time-base of a natural astrophysical process (a quasar in his article) to provide a reference clock to aid detection of a signal that has been amplified by a stellar laser/maser. The approach described here proposes to use pulsars, which offer greater timing stability than quasars, and is also not specific to self-amplified signals. We suggest that a beacon system aiming to transmit directly to a target recipient over interstellar distances could benefit from the implicit coordination available through pulsars.

Our Galaxy is estimated to have tens of millions of pulsars, distributed approximately in proportion to stellar density. Of those, around 20,000 to 30,000 are predicted to have an emission beam that sweeps past the Earth and will be detectable by our next generation radio telescope, the Square Kilometre Array (SKA) [2] [3]. So far, fewer than 3,000 of these have been discovered, due to the sensitivity limits of current telescopes. This will change when the SKA is constructed; one of its key science goals is the discovery of the entire population of visible pulsars in the Galaxy.

By limiting ourselves only to time-bases matching pulsar periods we can reduce the number of time-bases that SETI needs to probe. No pulsars have yet been discovered with a rotation period less than 1 millisecond, and the physics of neutron stars may rule out the possibility of periods much shorter than this. Our approach therefore immediately rules out all time-bases shorter than ~ 1 millisecond. Allowable time-bases will be substantially further reduced by requiring co-visibility of pulsars to both the transmitting and receiving civilizations. Although there are tens of millions of pulsars in the Galaxy, only a small fraction of these are visible from any given observing location. For each location in the Galaxy, the population of visible pulsars will be different, as determined by the orientation of the pulsar beam emission planes of each pulsar relative to that location (this "plane" is actually slightly conical, but this does not change the argument). However, we expect at most locations for there to be a small number of pulsars whose emission plane passes through that location and also the Earth's location. A beacon builder wishing to communicate with Earth could choose one of these co-visible pulsars and utilize a signaling method with a time-base matching that pulsar's period. On Earth, we choose an observing direction and assume that there is a putative beacon transmitter along that line of sight. Then for all known pulsars visible from Earth, we select only the subset of pulsars whose emission plane passes through the conical beam volume associated with our telescope's observing direction. A special case arises when there is a pulsar visible to us that lies on or near the observing line of sight, or the very opposite direction. In these cases we can be certain that the pulsar will also be visible to any beacon builder located between us and the pulsar, along the observation's line of sight. For pulsars in other directions on the sky, co-observability will depend on the pulsar's plane of emission and beamwidth. Given that the typical pulsar emission beam full width at half maximum is 5 degrees[1] at 1 GHz [6], the anticipated number of co-observable pulsars is a few tens based on existing pulsar catalogs, and ultimately several hundreds for all pulsars in the Galaxy.

While we might reasonably suppose that the transmitting civilization will have advanced astronomy capabilities and a complete, accurate database of all pulsars visible to themselves, including their emission plane orientation, we do not currently have this same level of knowledge on Earth. Our pulsar astronomers have been building up a catalog of all the pulsars detected to date, but we know the plane of emission for only a small number of them. It has not generally been a major concern to the pulsar community, as the particular plane angle has little impact on pulse time-of-arrivals. However, knowledge of this plane angle will gain importance over time as greater pulsar timing accuracy is demanded (e.g. for gravitational wave detection), so that its impact can be properly accommodated in timing models.

The point is that, if we know the planes of emission for our visible pulsars, then we can use this information to drop the majority of them from the list of time-bases to examine. The method will provide an increasingly

[1] The effective emission beam opening angle of a pulsar, hence its visibility, is also affected by its distance and the sensitivity of our instruments. For pulsars that are close and measured with our most sensitive instruments, the pulses will be detectable over angles larger than the estimated 5°. Someday it may be possible to discover all pulsars in the Galaxy given a telescope of sufficient sensitivity.

tighter constraint on candidate pulsars over time, as our catalog of pulsars and their emission plane orientations becomes more complete.

To get better estimates on the number of co-visible pulsars for a given observation direction, we propose to use a Monte Carlo model of the pulsar distribution in the Galaxy. This model will contain information about the probability of pulsar type and plane of emission. In the model, the Galaxy will be populated with pulsars following the appropriate spatial distribution, and each pulsar will be allocated an emission beam width from a distribution based on known pulsars, as well as a random orientation of the emission plane on the sky. For all locations in the Galaxy, we can ascertain the number of pulsars illuminating that location that also illuminate the Earth. In this way we can make a heat-map style plot showing the density of suitable pulsars over a sky map on galactic coordinates. This is expected to confirm that the method could be employed by beacon builders in any location within the Galaxy. As our pulsar astronomers gather and refine measured pulsar emission plane orientations, this simulation model can be progressively improved by inserting the actual pulsars into the model with their known beam characteristics.

Summary: The proposed approach provides a rationale for constraining the number of signaling timebases considered within wideband SETI searches. This can reduce an intractable computational problem to one that is manageable at real-time speeds in current radio telescope back-end processing systems, including the SETI Institute's Allen Telescope Array. This offers a new path forward to significantly increase the scope of resource-limited wideband SETI searches of the future, with a credible and defensible rationale.

Additional Information:

(A) This paper responds to Question 3 of the *Alien Mindscapes* article: How can we detect intelligent life?

(B) The development of a Galaxy-scale Monte Carlo simulation may be considered as a form of Big Data Analysis. The exercise will not initially require access to existing databases, but will create its own large simulated database. However, in the future we envisage consolidation of the simulated database with the expanding databases of observed pulsars and their properties.

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