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SETI in the Optical Spatial-Temporal Domain

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ABSTRACT

Traditional searches for extraterrestrial intelligence (SETI) or "technosignatures" focus on dedicated observations of single stars or regions in the sky to detect excess or transient emission from intelligent sources. The latest generation of synoptic time domain surveys enable an entirely new approach: spatial–temporal SETI, where technosignatures may be discovered from spatially resolved sources or multiple stars over time. Current optical time domain surveys such as ZTF and the Evryscope can probe 10–100 times more of the "Cosmic Haystack" parameter space than typical radio SETI investigations. Investigations with these surveys can also be conducted at a fraction of the cost, since they require only re-analysis of data already being gathered. However, SETI methodology has not widely utilized such surveys, and the literature is in need of new search algorithms that can incorporate signals from both the spatial and temporal domains. Here I describe the broad potential for modern wide-field time domain optical surveys to revolutionize our search for technosignatures, and illustrate some new example SETI approaches that utilize the spatial-temporal domain

1. INTRODUCTION

Despite more than half a century of activity, the Search for Extra-Terrestrial Intelligence (SETI) is a field of study very much in its infancy. Wright et al. (2018) note the volume of parameter space for SETI (or the search for a needle amongst the "cosmic haystack") at radio wavelengths has been barely explored, and that many obvious signals may indeed be awaiting our discovery. The lack of SETI activity by the astronomical community can be partially understood as due to funding limitations in recent decades, as well as social pressures against studying SETI experienced by professional astronomers and organizations (Wright & Oman-Reagan 2018).

Traditional SETI work also requires time-consuming observations, often through dedicated monitoring of nearby stars by radio telescopes. Such observing campaigns are expensive and difficult to obtain given the resource-limited nature of telescope allocation. Recent progress for a systematic "technosignature" search has been made

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by Breakthrough Listen (Worden et al. 2017; Isaacson et al. 2017), primarily at radio wavelengths (e.g. Price et al. 2018).

The SETI conundrum has always been not only "*What should we look for?*", but also *"When and where to look?"*. While Wright et al. (2018) suggest the completeness of our search of the "cosmic haystack" at radio wavelengths is akin to the ratio of a swimming pool compared to the Earth's ocean's ($\sim 10^{-20}$), SETI at optical wavelengths is surely many orders of magnitude less complete. However, new wide-field time domain surveys will enable us to greatly expand our search in two key dimensions of parameter space: 1) collectively observing nearly the entire night sky, and 2) providing time resolved monitoring over many years.

Surveys like the currently running Zwicky Transient Facility (ZTF Bellm 2014) and the upcoming Large Synoptic Survey Telescope (LSST Ivezić et al. 2008) will also be transformative in enabling both reproducible and cost-efficient SETI. By developing search strategies that utilize public survey databases and real-time "alert streams", both of which are being developed to facilitate a wide range of science goals from these facilities, optical survey SETI can be conducted automatically. As new search algorithms are developed, these databases can be quickly re-analyzed, providing a much-needed level of reproducibility and transparency that will help reduce the "giggle factor" stigma for SETI (Wright & Oman-Reagan 2018).

In this paper I explore the potential of wide-field time domain surveys for conducting new technosignature searches. In §2 I introduce several relevant surveys, and use the "Cosmic Haystack" search volume metric developed by Wright et al. (2018) to quantitatively compare these surveys to current radio SETI approaches. The data-driven spatial-temporal domain explored by these surveys necessitates a new generation of SETI approaches be developed. Technosignatures utilizing the spatial-temporal domain could include spatial over-densities of light curve signals and coordinated signals between multiple sources, for example. In §3 I discuss one such signal, where transiting planets around many stars act as a spatially distributed beacon network. Finally in §4 I discuss ideas for other search approaches, and the advantages in cost and reproducibility of conducting SETI with optical time domain surveys.

2. COMPARING OPTICAL SURVEYS TO RADIO

we need to be looking at big optical surveys, since they provide such amazing sky/time coverage

bright facilities have excellent sky and time coverage: ASAS-SN (Kochanek et al. 2017)

Evryscope (Law et al. 2015)

starting to probe fainter sources becomes a trade off for area and time coverage. Zwicky Transient Facility (Bellm 2014) for example surveys the sky every couple nights, but with only a single visit per source per night.

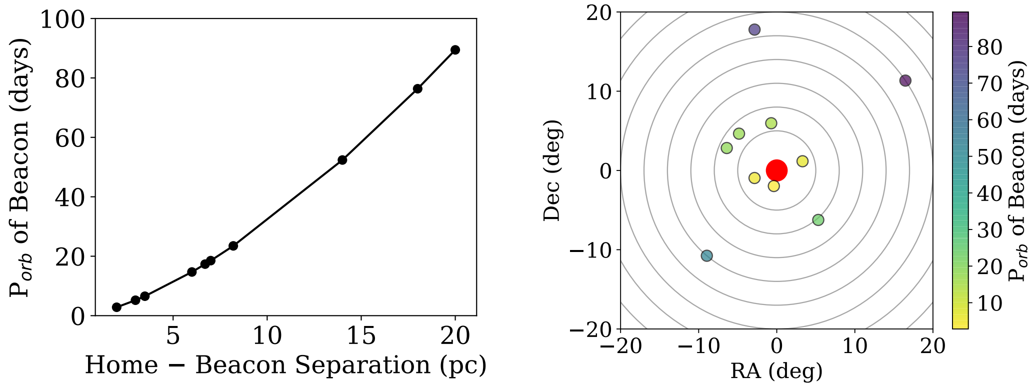

Figure 1. schematic figure of the signal to detect in 2 dimensions. ra,dec in arbitrary units. red circle in middle is the home system

space-based platforms designed for exoplanet searches provide very high quality light curves over months to years timescales. The *Kepler* and K2 missions (Borucki et al. 2010; Howell et al. 2014) produced 30-minute cadence light curves for ∼500,000 stars, with baselines ranging from ∼3 months up to 4 years. and TESS (Ricker 2014), as well as Gaia (Gaia Collaboration et al. 2016) provide incredible precision light curves

parameter space to search: - spatially coordinated events

3. TRANSITS AS A SPATIAL-TEMPORAL BEACON

3.1. *Coordinated Transit Networks*

imagine a Type N civilization with the ability to both travel to nearby star systems, and to build large enough structures in orbit around other stars to produce a visible transit in our data.

give the detailed example i have thought up.

becons placed at distances

for clarity, this is what the ideal signal might look like on the sky

this type of beacon network is advantageous because it points directly back towards their home. only a few systems actually need to be transiting from any given line of sight.

NOW THE FULL SIMULATION... - computation to do: if had 100 beacons, each placed at random orbital alignment, in 3d sphere around home system. - assume G stars, - odds of observing transit of a fixed sized object versus orbital distance... goes down. need that plot to figure out probability. - assume ET places beacons with uniform RADIAL density in 3d space out to some maximum distance (even # of systems as function of radial distance) in bins of 10pc out to 100 pc (i.e. 10 beacons in each 10pc bin) - orbital period is exact for each system, no bins of period - do Monte Carlo sim with these parameters to figure out how many transiting systems we'd observe

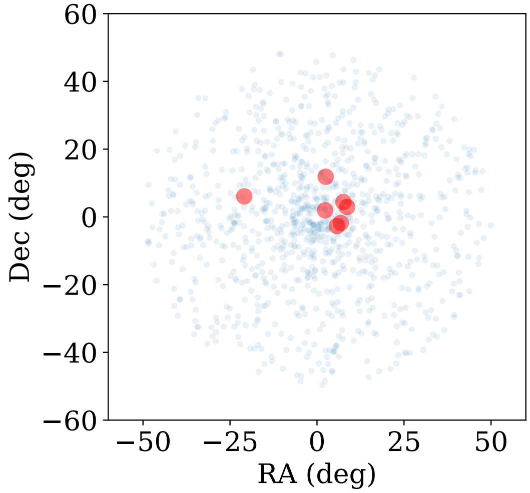

Figure 2. the model in 3 dimensions projected into the sky plane. 1000 simulated systems that span the galactic distance of 5-50 pc (blue) with 10 recovered transits highlighted (red). these would be hot Jupiters at the short P end.

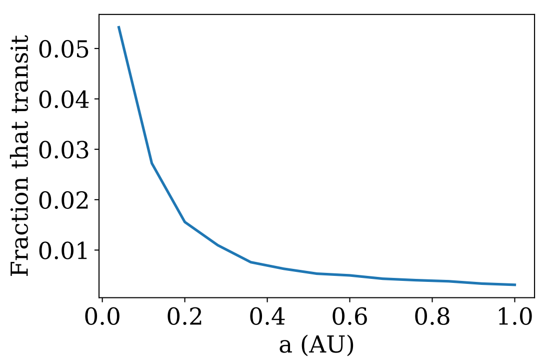

Figure 3. fraction of hot Jupiter-like systems recovered in 1000 realizations of our 1000-star simulation. This curve is dependent on the ratio of the occulter-to-star size, and the orbital period range sampled. The average from our model is 10 ± 3 systems recovered for these parameters.

—- make the plot for one MC realization of RA,Dec.... open circles for systems with no observed transits, colored for transits

IDEA: could improve the efficiency of these beacons if we consider a bit of galactic structure, aligning the median orbital inclinations of the beacon systems with the Galactic plane, and only allowing a smaller range of possible inclinations. How much more efficient would it be if we forced $i < 10°$, instead of $i < 90°$?

for a million system model w/ 90deg max, 0.46% total detection efficiency. by constraining the inclination to 10deg max, get 4.3% detection efficiency of planets. 30deg max gets 1.4%

PROBLEM: as Forgan (2017) note, an interstellar communications based on transits may only be stable for ∼10,000 years due to evolution of planetary orbits and relative

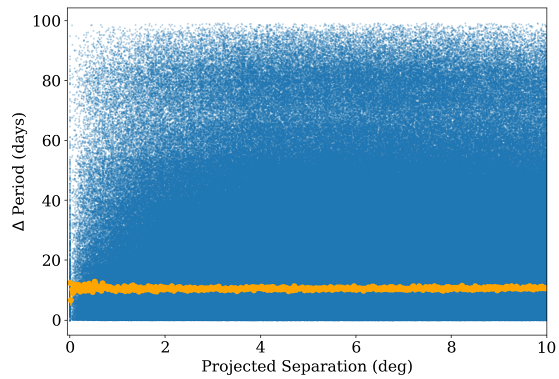

Figure 4. searching for correlation between transit periods and projected separations between all exoplanet systems out to 2deg in the Kepler data. median period differences are computed for bins of separation distance (orange points). there is no trend in these medians, indicating a distribution of orbital periods that are random on large scales.

motion between stars within the Milky Way. The beacon systems centered around the host system would have to be traveling as a moving group to maintain their respective trilateration signals, or have the transiting bodies actively over time. In other words, as the beacon systems moved relative to the ET host star due to differing Galactic orbits, the semi-major axis of the transiting bodies would have to be adjusted to compensate.

3.2. *Searching for Correlated Transits in Kepler*

we compute the 2-point correlation between all transits in the Kepler sample in 2D space (radius)

we find there is no correlation. Thats OK, but at least we searched

Coughlin et al. (2014) find some correlations that are apparently removed in KOI catalog creation... due to contamination by RRlyr or other thing? See also TCE histogram in Twicken et al. (2016)

4. DISCUSSION

so far we have focused on the need for developing SETI approaches that utilize the new spatial-temporal domain. The data streams from these surveys also enable many other search strategies that could be implemented. these might include: VASCO-type events, stars appearing or disappearing. (Villarroel et al. 2016) - Esp. stars appearing that do not have a Gaia DR2 detection, for example. - need to account for novae, etc... - stars disappearing will be very interesting

coordination/synchronization (Makovetskii 1977; Shostak 2004) - especially the SETI ellipsoid, a'la SN1987A (Lemarchand 1994) - could use galactic novae to provide time/place - -

unnaturals patterns of otherwise normal events - look for e.g. flares or novae that recur w/ prime or fibonacci sequences - see forthcoming paper

Surveys like ZTF (and soon LSST) publish real-time alerts of variability from sources. These alert streams could be monitored in real-time for signals as well: alerts from the stars within the “restricted Earth Transit Zone” (Heller & Pudritz 2016) - anytime we can see them w/ ZTF - especially at our opposition (i.e. when we transit) - with Gaia we can track stars that are leaving the ETZ as well, but might have seen us transit previously (or by the time the signal reaches us)

alerts from known exoplanet host systems, especially coinciding with any known transit conjunction (mid-transit), - allow some tolerance window to account for TTVs

The cost of deploying such SETI is remarkably low, since they can “piggyback” on databases and search tools being developed for the primary science drivers of each survey (e.g. transients for ZTF).

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