OUR SKY NOW AND THEN: SEARCHES FOR LOST STARS AND IMPOSSIBLE EFFECTS AS PROBES OF ADVANCED EXTRATERRESTRIAL CIVILIZATIONS

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ABSTRACT

Searches for extraterrestrial intelligence using large survey data often look for possible signatures of astroengineering. We propose searching for physically impossible effects caused by highly advanced technology by carrying out a search for disappearing galaxies and Milky Way stars. We select ~10 million objects from USNO-B1.0 with proper motion speeds \( (\mu < 20 \text{ mas yr}^{-1}) \) imaged on the sky in two epochs. We search for objects not found at the expected positions in the Sloan Digital Sky Survey (SDSS) by visually examining images of ~290,000 USNO-B1.0 objects with no counterpart in the SDSS. We identify some spurious targets in the USNO-B1.0. We find one candidate of interest for follow-up photometry, although it is very uncertain. If the candidate eventually is found, it defines the probability of observing a disappearing-object event in the last decade to less than one in one million in the given samples. Nevertheless, because the complete USNO-B1.0 data set is 100 times larger than any of our samples, we propose an easily accessible citizen science project in search of USNO-B1.0 objects that have disappeared from the SDSS.

Key words: astrobiology – extraterrestrial intelligence – surveys

1. INTRODUCTION

The possibility of finding intelligent life beyond our own planet is an ongoing dream. So far, we have not seen or heard the slightest hint. Efforts to search for indirect signatures of astroengineering from extraterrestrial civilizations in survey data are currently expanding and these searches often make use of large data sets. Such studies have the advantage that they can yield new insights into important astrophysical phenomena as an exciting by-product. Some of these efforts have targeted stars in the Milky Way (e.g., Jugaku & Nishimura 1991; Timofeev et al. 2000), while others have turned to extragalactic scales (e.g., Annis 1999; Wright et al. 2014a, 2014b; Griffith et al. 2015). Assuming that all advanced Kardashev II-IV civilizations (Kardashev 1964) attempt to build Dyson spheres (Dyson 1960) throughout their galaxy to harvest energy from stars, a significant fraction of the waste heat from the Dyson spheres will be irradiated as mid-infrared emission. When looking for high-consuming alien civilizations producing a waste-heat luminosity of ~10^{11} L_☉ from each galaxy, it was shown with Wide-field Infrared Survey (WISE) data (Wright et al. 2010) that such super civilizations must be extremely rare (Wright et al. 2014b). Recent studies using other methods (Zackrisson et al. 2015; Lacki 2016; Olson et al. 2015) support the conclusion that Kardashev II-IV civilizations in the local universe are very rare and difficult to find. The difficulty to distinguish between mundane causes and the signatures of astroengineering, further complicate the searches.

In this paper, we propose replacing the search for possible signatures of astroengineering with a search for impossible (or nearly impossible) effects for conventional astrophysics. Quoting Arthur C. Clarke’s Third Law, “Any sufficiently advanced technology is indistinguishable from magic.” Examples of such hypothetical effects include a galaxy that rapidly and strongly changes redshift or apparent size over the course of a few years, or a galaxy, previously visible on the sky, that suddenly disappears entirely from its location. Also, a Milky Way star that disappears entirely without an accompanying supernovae is equally interesting and can indicate the existence of an advanced extraterrestrial civilization with an interest in hiding a star from their enemy. However, it can also point toward unknown or exotic physics, like stars disappearing into wormholes.

We perform a search for objects lost from our sky over the last decades. A similar idea of constructing an anti-transient survey of stars in nearby galaxies to search for the hypothesized failed supernovae from massive stars, was originally proposed by Kochanek et al. (2008), and later also carried out by Gerke et al. (2014). Failed supernovae can only happen to stars within the mass range of 18–25 solar masses and are significantly less common than optically bright supernovae. In 2015, two candidates for failed supernovae were detected (Reynolds et al. 2015) in nearby galaxies. It should be noted that not a single supernova in the Milky Way has been detected in the last 150 years; therefore, the number of failed supernovae should be zero.

In this paper, we conduct a study and present results from a search for advanced extraterrestrial civilizations by looking for objects that mysteriously disappeared from the sky in the last decade. We use the United States Naval Observatory (USNO) B1.0 catalog (Monet et al. 2003), which stores information about roughly one billion objects and is complete down to \( v \sim 21 \). The USNO-B1.0 objects have negligible proper motion (<20 mas yr^{-1}) and were all detected during at least two epochs in the Palomar Observatory Sky Survey (first POSS survey: 1950–1966; second POSS survey: 1977–1999) before being included in the catalog. This minimizes detections of asteroids, comets, fast-moving objects, and chance detections.

Afterward, we match these objects against a third epoch using the Sloan Digital Sky Survey (SDSS; York et al. 2000) and search for objects that have disappeared. The SDSS is complete down to magnitude \( r \sim 22 \) (ugriz) and overlaps partially in sky coverage with USNO-B. By comparing the USNO-B1.0 and SDSS catalogs, it is shown that USNO-B1.0 is 100% complete for unblended stars (Monet et al. 2003).
### Table 1
Selection Constraints for the Parent Samples from USNO-B1.0

| Parameter | NDET (N) | Weak (N) | Big (N) | NDETVar |
|-----------|----------|----------|---------|---------|
| Character? | Static Obj. | Any | Static | Variable |
| R.A.Lower J2000 | 110 | 110 | 110 | 110 |
| R.A.Upper J2000 | 265 | 260 | 260 | 265 |
| decl.Lower J2000 | <3 | 0 | 0 | <3 |
| decl.Upper J2000 | 75 | 70 | 70 | 75 |
| Mean epoch | ... | year 1949–1966 | ... | ... |
| Number of detections | ... | ... | ... | >4 |
| 1σ-error in right ascension R.A.err at 1st epoch (100 mas) | ... | ... | <20 | ... |
| 1σ-error in declination decl.err at 1st epoch (100 mas) | ... | ... | <20 | ... |
| Proper motion pmra (mas) | <20 | <20 | <20 | <20 |
| Proper motion pmdec (mas) | <20 | <20 | <20 | <20 |
| Error in proper motion pmra.err (mas) | ... | <1 | <10 | ... |
| Error in proper motion pmdec.err (mas) | ... | <1 | <10 | ... |
| 1st red observation repoch−1 (mag) | <18 | 11 < r < 20 | <17.5 | <18 |
| 2nd red observation repoch−2 (mag) | <18 | 11 < r < 20 | <18.5 | <18 |
| 1st red observation bepoch−1 (mag) | <18 | ... | ... | <18 |
| 2nd red observation bepoch−2 (mag) | <18 | ... | ... | <18 |
| Distance (X) between photo-center and mean position 1st epoch repoch−1 (arcsec) | ... | <1 | ... | ... |
| Distance (Y) between photo-center and mean position 1st epoch bepoch−1 (arcsec) | ... | <1 | ... | ... |
| Distance (X) between photo-center and mean position 2nd epoch repoch−2 (arcsec) | ... | <1 | ... | ... |
| Distance (Y) between photo-center and mean position 2nd epoch bepoch−2 (arcsec) | ... | <1 | ... | ... |

### Table 2
Sample Sizes After Every Step of the Cleaning

| Samples | NDET (N) | Weak (N) | Big (N) | NDETVar |
|---------|----------|----------|---------|---------|
| Nstart | 7352942 | 1607582 | 10310181 | 1041330 |
| NFootprint | 4921685 | 1305447 | 4906527 | 802295 |
| NNomatch | 186262 | 30566 | 53569 | 17761 |
| Npreliminary | 13 | 110 | 25 | 0 |

Note. Objects for which no nearest neighbor can be found, or where the nearest neighbor is at least \( \omega > 0.15 \) arcmin away, are counted in \( N_{Nomatch} \).

Any candidate found must be explored with follow-up photometry to separate it from natural anti-transient events, e.g., variable objects. (We only consider an object really “disappeared” if it does not reappear during any follow-up observations.) Finally, we use this study to set a limit on the probability for observing a disappearing-object event with the wide-field surveys.

### 2. Samples and Methods

We use the NASA/IPAC Infrared Science Archive interface to access USNO-B1.0 data. It is not possible to download samples larger than about 10 million objects due to technical limitations on both the server page and our own technical capacities. Therefore, we construct parent catalogs based on various selection criteria. We mark the constraints for each parent sample in Table 1. One common constraint in all samples is that we only use objects with low proper motion (<20 mas yr\(^{-1}\)).

Variability near the detection limit of the USNO-survey can cause some objects to drop out of the catalog. Cataclysmic variables are example of stars that might appear or disappear between the USNO-B and SDSS surveys. Furthermore, static objects could disappear if they are weak and the background sky is bright. The 1σ error in the r-band magnitude error is about \( |\Delta r| \sim 0.25 \) mag, and we define “static” objects as those showing no signs of variability between the first and second epochs in USNO-B1.0 so that \( |\Delta r| < 0.25 \) mag. “Variable” objects have \( |\Delta r| > 0.25 \) mag. The NDET and Big samples contain only static objects, NDETVar only variable ones, while the Weak sample contains both static and variable ones.

We use the Footprint function in the SDSS Casjobs to cross-match the objects to SDSS Data Release 12 (DR12). The Footprint function checks if a coordinate is within the SDSS scanned field. For objects within the scanned field, we search for the nearest primary neighbor in SDSS DR12 and the angular distance \( \omega \) (arcminutes) to each object. For those objects for which no near primary photometric neighbor can be found in the vicinity, the distance is replaced by “NULL.” We only keep objects where the distance is “NULL” or objects that have a neighbor at an angular distance \( \omega > 0.15 \) arcmin. The sample sizes at the different steps can be found in Table 2.

Using the SDSS Object Explorer, we visually examine the list of targets one by one. For the majority of the objects, an object is found in the center of the window despite being marked as “null,” showing that they were missed by the SDSS targeting pipeline. We ignore these. We also ignore all objects showing a black “dead” stripe, near blended stars, diffraction spikes, and other visible artifacts in the SDSS. A tiny fraction of the images appear normal without any recognizable artifacts and yet have no object in the center of our image. These constitute our preliminary objects of interest that might harbour important candidates.

1 http://IRSA.ipac.caltech.edu
3. RESULTS

From the four sample selections, we obtain in total 148 preliminary objects (see Table 2) of interest that are missing in the SDSS and have no primary photometric object detected in the vicinity of the SDSS images. The number of discovered preliminary objects is also marked in Table 2.

Most of the objects from the weak sample classification have zero proper motions and weak r-magnitudes of $r \sim 19$, close to our selection limit. One may wonder whether we are dealing with detection faults and enhanced noise. In order to find out if the reported event truly is an object lost in the third epoch, we must be sure of two things: first, that the objects were truly there from the beginning (removing false positives), and, second, that they truly were lost (removing false negatives).

3.1. False Positives in USNO-B1.0? Artifacts?

Artifacts and false detections in USNO-B1.0 seem like the easiest ways to explain the apparent missing objects. Whatever the artifact is, it must be the type of artifact that appears in both the first and the second survey and could appear over and over again with the same instrumentation. Diffraction spikes and halos near bright stars could be present and cause repeated misidentification by the survey machinery. Scratches and damages on the photometric plug plates, cosmic rays, or a spontaneous fly-over by a swarm of ducks during the photon collection are events with a negligible probability of happening during two different epochs for the same spot on the sky.

Luckily, many of the spurious objects in the USNO-B1.0 were identified by a clever computer algorithm and are stored in a list (Barron et al. 2008). Only a handful of our interesting targets are found within 5 arcsec from the listed positions of the spurious targets.

However, false positives can also happen if the sky subtraction or signal are quite weak relative to the background noise. Coincidences due to erroneous combinations of objects with high proper motion at different epochs can also create a false positive.

Therefore, we visually examine the original POSS-1 and POSS-2 images that were used to construct the first and second epochs of the USNO-B1.0 survey, obtainable from the Digitalized Sky Survey. Using the central coordinates of the targets, we insert them into the target search and see if any object is visible in the center of the POSS-1 images. For the majority of the targets, we cannot see anything even in POSS-1, suggesting that these objects have errors in their proper motions and predicted J2000 positions or were just noise (and no real detections). However, some preliminary candidates survive this check.

3.2. False Negatives in SDSS?

An object can be lost from the SDSS if the photometry is of lower depth. However, SDSS goes deeper and many more faint stars are visible in the SDSS Object Explorer than in the POSS images.

For every object found in POSS-1 and POSS-2, we must compare the relative position in its field to the relative position in an SDSS image. We note that almost every object is found in SDSS where it was supposed to be from the beginning—at its expected position, but with disagreement in SDSS and USNO-B1.0 coordinates.

Summarizing the three typical USNO-B1.0-specific errors that seem to be present upon visual inspection in Table 2, we find the following.

1. (False positive) We see no object at all in the center of the original POSS-1 image or some very weak signal that could be noise. More than half of the errors belong to this category. To know the probability of false positives of this nature to occur, it would be advantageous to obtain an estimate of how probable it is to get $n$ independent false detections at the same spot in the sky in both POSS-1 and POSS-2. (This is beyond the scope of this study but will be implemented once we redo it with the full USNO-B1.0 catalog.)

2. (False positive) We see an object clearly in one survey, but in the other survey nothing, or an artifact (e.g., a stripe), is seen.

3. (False negative) There are objects in the center of both POSS-1 and POSS-2, but the coordinates are slightly offset between POSS and SDSS. The number of “preliminary candidates” belonging to this category is about 10% of the cases.

Not unexpectedly, the number of “preliminary candidates” identified drops dramatically if requiring an object to have at least four detections. The requirement eliminates false positives due to faintness and might improve the quality when working with data from noisy photographic plates. The preliminary candidates originating from the NDET sample almost all have slightly offset coordinates between SDSS and POSS. This demonstrates the need to use samples with at least four detections in the USNO-B1.0 when searching for missing objects. We know that 40% of all USNO-B1.0 objects at the northern hemisphere have five detections, but unfortunately we cannot access the full sample.

3.3. A Dubious Candidate

From the entire study, only one candidate survives our rigorous investigation and cannot be rejected. It originates from the weak sample and has the coordinates (R.A., decl.) = 224.402387, 18.417250 (J2000) or $14^h57^m36.57^s + 18^\circ25'02.10''$.

Pictures of the candidate in the POSS-1 Band E (image taken 1950 March 16, resolution 1.6 pixel$^{-1}$), POSS-2 Band F (image taken 1992 March 10, resolution 1.0 pixel$^{-1}$) and SDSS and are shown in Figures 1 and 2. They are taken directly from CDS Portal. We can see the object clearly in the POSS-I image. The object is still visible very faint in the red survey of POSS-II, but no longer in the SDSS. Another view is through the interface of The STScI Digitized Sky Survey, included with 2 $\times$ 2 arcmin large zoom-ins of the same region.

For the candidate, we search for possible counterparts within 5 arcsec in the infrared surveys 2MASS, WISE, and AKARI and the VizieR catalog. An infrared counterpart could indicate that the lost USNO-B object is physically present at the expected position but was undetected in the SDSS. However, if the lost USNO-B object that previously was detected is now only observable in the infrared, that is also a good cause for speculation—could perhaps a Dyson sphere have been built around the star during these 60–70 years? However, the object

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2 http://cdsportal.u-strasbg.fr
3 http://stdatu.stsci.edu/
cannot be found in any of the other surveys, which excludes this possibility. Also in the intermediate Palomar Transient Factory public survey,\(^4\) in a sample of images taken from 2009 to 2010 in the R\(_{\text{band}}\) and G\(_{\text{band}}\) bands, nothing is seen.

Assuming this candidate eventually is found with follow-up photometry, we determine the probability \(p\) to detect a truly disappearing object from the survey during a decade (the time difference between the POSS-II and SDSS mean epochs) to be less than \(p < 10^{-6}\). However, since impossible effects are not a necessary condition for a super-civilization to exist (only an indicator of super civilizations if finally detected), the probability limit should not be translated into a limit on the prevalence of super civilizations. Moreover, the probability is not equal to the total probability of observing an object disappear in the Milky Way. Considering the age of a galaxy (~\(10^{10}\) years), a decade is an extremely short time frame and

\(^4\) http://irsa.ipac.caltech.edu/applications/ptf/
brings a large uncertainty into the given estimate. The total number of stars in the Milky Way \(N_{\text{MW}} \sim 10^{11}\) is much larger than the number of stars in any of our samples \(N \sim 10^6\). This means a large number of stars would need to disappear in the Milky Way during this short time for us to have a chance of noticing the effect in our samples that cover just a small fraction \(f \sim 10^{-5}\) of the entire set of stars. Therefore, even if a Milky Way star disappeared between the POSS and SDSS surveys, it is unlikely we will notice it in our samples. To set a truly realistic limit on observing the disappearance of an object in the Milky Way, we need much larger samples.

3.4. Efficiency of the Method

Small errors in astrometry might give slight differences in coordinates in USNO-B1.0 and SDSS. Even when SDSS claims to have found a match for the USNO-B1.0 object, it is not necessarily the same object that is found at the given position. Its properties are shown in Table 3.

In order to correctly estimate the upper bound on the probability of detecting a missing object event, we must estimate the efficiency of the successful matches, for example, if only 15% of all successful matches target the initial USNO-B1.0 object, it means that the lower bound of the probability is highly underestimated by a factor of seven.

We want to examine if they are the same objects we found in both surveys at the given positions. We take 10 galaxies with SDSS matches within 1.2 arcsec (742913 objects) from the NDETVar sample and compare the relative positions of the objects in the fields in the POSSII/UKSTU Red Survey (via STScI Digitized Sky Survey) and SDSS. Indeed, 10 out of 10 objects are the same ones, showing the robustness of the method.

However, it should be noted that when looking for variability in galaxy samples from Villarroel & Korn (2014) through the SDSS Casjobs interface (Table: USNO), we find that about 90% of the galaxies at \(z < 0.2\) show variability on scales of \(|\Delta r| > 0.25\) mag and/or \(|\Delta b| > 0.25\) mag in the USNO-B1.0—an unphysical result. It is possible that magnitude measurements for extended objects in the USNO catalog have big uncertainties due to imprecise targeting. For point-like objects, it will be less likely.

4. DISCUSSION

Using measurements from three different epochs, we have searched for disappearing objects in the sky during the last decade. We find one candidate object, though an uncertain one due to its faintness in POSS-2. An improved image analysis is needed to determine with confidence whether it is a real detection, as was originally reported in USNO-B1.0.

If real, the object could be an extreme, but natural anti-transient: a cataclysmic variable, an eclipsing binary (Lipunov et al. 2016), or a highly variable quasar whose luminosity fell below the detection limit of the SDSS. If so, follow-up studies
with more powerful telescopes surely will reveal its presence at the expected position and teach us more about the nature and physics of the object. However, if it is not found even with the largest telescopes, this opens up the opportunity for fascinating, new interpretations.

If the object eventually is reobserved, it sets the probability of identifying entirely vanishing objects to be less than one in one million during the last decade with the given samples. This is not so little—our own Galaxy harbours about 400 billion stars, USNO-B1.0 contains information for 1 billion objects, and the upcoming Gaia will bring new possibilities with its improved astrometry for Milky Way stars. Now, we have only studied objects with very small proper motions, neglecting stars close to the solar system. However, if we use all objects in the USNO-B1.0 catalog with at least four detections (about 40% of the entire catalog) and with accurately measured coordinates and proper motions, we can use a similar method to visually sort out objects that are genuinely missing in images from the SDSS, APASS, Pan-Starrs, and iPTF surveys. The positions of the preliminary targets can be further cross-matched against the first Gaia data release. With the multitude of surveys taken during slightly different years and the large number of images one must examine, this gives opportunity for an excellent citizen science project where volunteers only have to determine if an object is seen or not at the center of an image. Citizen science has already led to fascinating discoveries, e.g., the discovery of the unusual light curve of KIC 8462852 (Boyajian et al. 2016). Finally, we hope for a fresh remake of the SDSS in the future, adding one epoch of observations, so that other effects can be probed and examined by comparing the properties of objects in the current SDSS and the reobserved SDSS. The full potential of this study waits to be explored with the Large Synoptic Survey Telescope and improved methods of identifying lost objects from our ever-changing sky.

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