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A New Search for μs Time Scale Radio Pulses

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Abstract. We describe a new search for intrinsically short (μs) dispersed pulses at 21 cm. This search uses coherent de-dispersion, implemented in a distributed computing framework. It will have a sensitivity of 10^{-18} W/m^2 and cover the Arecibo sky $\sim$ 3 times.

1. Introduction

This paper describes a planned search for intrinsically short (μs), dispersed pulses at a wavelength of 21 cm. This search, known as AstroPulse, takes data recorded for SETI@home, and analyzes it using coherent de-dispersion. This is made possible by distributing the computation over the internet to volunteers who donate their spare computer time.

Section 2 describes the technical side of the new search - the data set, signal processing algorithm, and implementation with distributed computing. Section 3 describes the astronomy we hope to accomplish. Possible sources include evaporating primordial black holes, pulsars, and extraterrestrial civilizations.

2. The New Search - AstroPulse

2.1. Data Set

The data set which will be used for the pulse search has been recorded at NAIC Arecibo Observatory from 1998-2002 for use by the SETI@home project. For a detailed description of the receiver hardware and observation strategy, see Werthimer et al. (2001). Here we summarize the relevant points.

The data collection for SETI@home uses an interesting, non-traditional approach. In order to maximize sky coverage and observation time, the data is collected from a line feed mounted across the dish from Arecibo's Gregorian dome. This results in a view of the sky which is always moving. As an observer using the Gregorian tracks a spot on the sky, our beam moves in a arc at twice sidereal rate. This enables us to observe with near 100% efficiency (since we are always recording "piggyback" on other observations) - covering approximately one Arecibo sky per year.

A 2.5 MHz subband centered on 1.42 GHz is split off to be analyzed by SETI@home. The two sign bits (real and imaginary) from this band are recorded onto DLT tape, then sent back to Berkeley, where they are split up and sent out over the internet to volunteer computers for analysis. The key parameters of our data set are summarized in Table 1. We have been running for about 3 years so far, and have 50 terabytes of data stored on tape.

Table 1. Summary of search parameters

Telescope	Arecibo Observatory - 300 ft. dish
Beamwidth	0.1°
Center frequency	1420 MHz
Bandwidth	2.5 MHz
Quantization	1-bit complex
System temperature	70 K
Sky coverage	1 AO sky per year
Observation time	3 years
Sensitivity	10^{-18} W/m^2

2.2. Coherent De-dispersion

One of the unique features of this search is that it is the first pulse search to use coherent de-dispersion in a "blind" fashion - we have no previous knowledge of a specific dispersion measure (DM) to examine. The reason this hasn't been attempted before is due to the enormous computing power required. We are able to afford this by implementing a distributed computing scheme, as will be described later.

The issue, as will be familiar to any pulsar astronomer, is that radio pulses travelling through the interstellar medium (ISM) become dispersed, or spread out in time. Due to plasma interactions, electromagnetic waves of different frequencies travel at different speeds through the ISM, with higher frequency waves travelling faster. This effect becomes more pronounced for high bandwidth signals, such as pulses. By contrast, narrowband signals will only experience a slight smearing. For frequencies much greater than the plasma frequency of the ISM, dispersion vanishes, and is not an issue in optical astronomy (for example, pulsed optical SETI doesn't need to take dispersion into account).

However, this is not all bad. Since dispersion is a coherent effect (preserving the phase of the signal), it can be corrected for, and the full strength of the signal can be recovered. The way to do this is to properly phase shift each frequency component in such a way as to make the original pulse line back up. This essentially amounts to a convolution by an appropriate chirp function. This needs to be done for each DM to be examined. Even implemented with FFT convolution, the computation will scale roughly as $O(N^2 \log N)$. At our bandwidth of 2.5 MHz, we calculate that to analyze the data in real time would require a computing power of 0.5 TeraFLOPs[1]. For comparison, a average desktop PC has a processing speed on the order of 1 GigaFLOP.

2.3. Implementation / BOINC

The solution to the computing problem is provided by another project our group is working on - the Berkeley Open Infrastructure for Network Computing, also known as BOINC. This is a software framework that will generalize much of the knowledge and expertise gained by building and running SETI@home.

AstroPulse will follow SETI@home as a public distributed computing project Volunteers download a screen saver from our website which performs data analysis when their computers would otherwise be idle.

Currently, any group wishing to pursue a project such as this needs to build all the required software from scratch. As SETI@home has over 4 million registered volunteers, and a total of 50 terabytes of raw data, this is not a simple task. BOINC will be a major help to distributed computing projects trying to get started. It takes care of most of the "bookkeeping" involved - all that needs to be supplied is a specific science application.

Since AstroPulse is a relatively small scale project, requiring only several thousand home computers, and uses a fairly simple (if time consuming) algorithm, it is a ideal beta-test for BOINC, and the development of the two projects is proceeding in parallel.

3. Possible Sources

As μs scale radio pulses are a unobserved phenomenon as of now, there is much speculation as to possible mechanisms for generating them. Here we describe a few such scenarios.

3.1. Evaporating Black Holes

The initial motivation for this search was a suggestion from Aaron Golden that we look for the signature of evaporating primordial black holes (PBHs). This was first postulated by Rees (1977), and has been the subject of a few searches so far. For a summary of previous efforts, see Phinney & Taylor (1979). Our search is at least 100 times more sensitive than the last effort, and we have much more observation time as well.

The basic physical process involved is Hawking radiation, in which a black hole slowly loses energy by radiating as a black body. The temperature is inversely proportional to the mass ($T \propto 1/M$), so the process will accelerate as time goes on. Eventually as the mass nears zero, there will be a short final burst of energy. The specifics of this final stage depend on details of fundamental particle physics at high energies, and as such are still controversial. Some theories

[1] 1 FLOP = One floating point operation per second, ie multiplying or adding two numbers

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predict a radio pulse similar to what we are looking for, while others predict the pulse to be most visible in gamma rays.

3.2. Fast Pulsars

So far the fastest pulsar discovered is PSR1937+21, with a period of 1.6 ms. Whether this represents a lower limit on pulse period is still an open question experimentally. Our approach is somewhat different from usual pulsar searches in that we use a small bandwidth, but a coherent de-dispersion. Usual pulsar searches use incoherent de-dispersion, but make up for it by examining a larger bandwidth. By adding a fast folding algorithm into AstroPulse, we hope to be sensitive to this type of signal as well.

3.3. Extraterrestrial Intelligence

Single dispersed pulses are a class of signal which has not been extensively examined in a SETI context. Most radio searches have concentrated on narrowband signals as opposed to a wideband signal such as a pulse. SETI@home has algorithms in place to look for pulsed signals of smaller bandwidth, down to ~ 1 ms pulse widths.

Another possibility is that a civilization intentionally creating a beacon for extraterrestrial astronomers would choose to create "pulses" which have a negative DM. Natural dispersion always causes higher frequency components to arrive first. A signal in which the low frequencies arrive first would stand out as obviously artificial. As a check on this, as well as to establish our background noise limit, we will be examining both positive and negative dispersion cases.

4. Conclusions

While the possible mechanisms for generating μs pulses are somewhat speculative, this project is an important step towards expanding the parameter space which has been explored for astronomical signals, both for SETI and for astrophysics. As well as being important scientifically, it will carry on the tradition of public involvement which SETI@home has started, by asking the public to volunteer computer time.

Currently, work is ongoing for both BOINC and AstroPulse. We hope to have a beta-test version ready for testing by the end of the year, and the full release sometime in 2003. For more information, see http://seti.berkeley.edu/

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