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SETI scientific activities in Sardinia: Search for ET, pulsars and Fast Radio Bursts

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Abstract. The Sardinia Radio Telescope, which was inaugurated in 2013, is getting ready to participate in the Search for ExtraTerrestrial Intelligence (SETI) observations. This involves, in collaboration with the SETI collaboration and the "Breakthrough Listen initiative", the onsite installation of the SERENDIP VI setup for SETI observations. In parallel, a scientific team at the Cagliari Astronomical Observatory is becoming acquainted with SETI search algorithms: both standard algorithms using the Fast Fourier Transform; and more versatile algorithms using the Kahrunen-Loève Transform (KLT) as well as Wavelets. The team is also investigating the possibility to pursue, with the SERENDIP VI setup, the simultaneous search for Extraterrestrial Intelligence, pulsars and Fast Radio Bursts.

Key words. Sardinia Radio Telescope, SERENDIP VI, pulsars, FRB

1. Introduction

Since 2013, a number of technological and scientific staff of the Cagliari Astronomical Observatory [1] (OAC) are involved in developing SETI activities at the Sardinia Radio Telescope (SRT) [2]. A thorough description of OAC's efforts in SETI are described in Melis et al. (these proceedings): this includes a description of SRT as a SETI facility, both in piggy-back mode and for targeted searches; the SERENDIP VI setup at SRT which is currently under development; as well as a description of the KLT and Wavelets algorithms. In this paper, we discuss the efforts to combine the search for ExtraTerrestrial Intelligence, pulsars and Fast Radio Bursts (FRBs) at SRT.

[1] http://www.oa-cagliari.inaf.it/
[2] http://www.srt.inaf.it/

2. SETI data analysis

While the technological team works on the installation of the SERENDIP VI setup for future SETI data acquisition, the scientific team is learning how to perform the analysis of SETI data, through a collaboration with the Breakthrough Listen (BL) program at UC Berkeley. This involves the testing of SETI detection software such as BL's GPU accelerated software spectroscopy suite on BL baseband data from the Green Bank Telescope and the Parkes telescopes. In parallel, the team, also in collaboration with UC Berkeley, is developing KLT algorithms which are being tested on BL data (Melis et al. 2016).

3. Pulsars

The data collected for SETI at radio telescopes are versatile and can also be used to search for exotic objects such as pulsars. Discovered in 1967 by Jocelyn Bell, the original radio signals (received as pulses) were so regular that they were thought to be emitted by intelligent life; these "pulsars" were thus dubbed LGM for "Little Green Men". It was later found out that the radio pulses were not emitted by intelligent life but rather by fast-rotating neutron stars. Their rotation periods range from roughly 1 ms to 10 seconds. They are highly magnetized and emit radio waves in the form of radio beams emanating from the star's magnetic poles. Those beams reach the Earth's line of sight only once per rotation of the pulsar: pulsars thus act as "cosmic lighthouses" where radio telescopes on Earth observe a series of pulses. Millisecond pulsars (with periods in the order of 1 -2 30 milliseconds) are particularly interesting since they are extremely stable. The concept of "pulsar timing" was born: by monitoring the arrival times of the radio pulses at Earth's radio telescopes (we can predict the pulse arrival times to about 10 nanoseconds over one year!), we can determine pulsar properties with very high accuracy. In fact, after a few years of collected data, the rotation period can be known to 15 significant figures. One can also determine the dispersion measure, or the amount of interstellar dispersion between the pulsar and Earth; as well as orbital parameters if the pulsar is in a binary. In particular, the estimation of orbital parameters in binary pulsars allows the testing of general relativity and alternative theories of gravity in the strong-field environment of the neutron star. In addition, the monitoring of a large sample of precise millisecond pulsars, a so-called "pulsar timing array", allows the detection of deformations in the spacetime between Earth and the pulsar, which would be caused by gravitational waves emitted by, for example, pairs of supermassive black holes in distant galaxy mergers (Perrodin & Sesana 2017).

3.1. Pulsar science at SRT: pulsar timing

SRT takes part in the monitoring of an array of precise millisecond pulsars as part of the European Pulsar Timing Array (EPTA). Five large European radio telescopes observe pulsars and later combine their datasets, involving: the 100-m Effelsberg Telescope (Germany), the 94-m equivalent Nancay Radio Telescope (France), the 94-m equivalent Westerbork Synthesis Radio Telescope (The Netherlands), the 76-m Lovell Telescope (UK), and the 64-m Sardinia Radio Telescope (Italy). At SRT, EPTA observations generally involve the monitoring of pulsars at L-band, P-band and S-band. We show in Fig. 1 the observation of the millisecond pulsar J1713+0747 at L-band with SRT.

In addition, the Large European Array for Pulsars (LEAP) project, which is part of the EPTA and was supported by an ERC advanced grant (2M euro, PI: M. Kramer), officially ran from 2009-2014 and was later continued thanks to local funding at each institution. The LEAP project involves the simultaneous monitoring of millisecond pulsars at all five EPTA radio telescopes (Bassa et al. 2016) (Perrodin et al. 2016). The simultaneity of the observations allows us to find the precise offsets between the telescopes and to add the data coherently. The resulting signal-to-noise of pulsar signals increases linearly with the number of telescopes, as opposed to the square root of the number of telescopes in the case of non-simultaneous observations. With the added signal-to-noise, the LEAP experiment is essentially equivalent to a 196-m radio telescope. This high sensitivity allows us to search for gravitational wave signatures in pulsar data over several years or decades. While detecting gravitational waves in the nanohertz frequency range would be groundbreaking, we can, in the meantime, find stringent limits on a background of supermassive black hole binaries.

At SRT, we also monitor pulsars with a neutron star companion, i.e. double neutron star binaries, which allow us to test general relativity in the strong gravity limit. Eclipsing binaries are also a focus of SRT research.

3.2. Pulsar science at SRT: pulsar searching

In order to search for gravitational wave signatures and test the strong gravity regime around pulsars, we need to find more pulsars. Pulsar searching can be done at L-band, P-band with SRT's dual-band LP receiver. A new, 7-beam S-band receiver was funded by the Sardinia region in 2013, was built and saw its first pulsars in 2016 (Valente et al. 2014). The S-band frequencies are particularly well-suited to search for millisecond pulsars in the Galactic Center. The pulsar search software capabilities at OAC and SRT are currently being upgraded to involve GPUs. OAC is also involved in FRB searches and their follow-ups thanks to the SUPERB collaboration.

3.3. Pulsar instrumentation at SRT

The currently-used pulsar backend instruments at SRT include a Parkes Digital Filberbank (PDFB) backend as well as a ROACH backend. The instruments have been used to observe mostly at L-band (1300-1800 MHz) and P-band (305-410 MHz). A second ROACH board is being installed and will allow the use of two ROACH boards to observe in L-band and P-band simultaneously; the use of a GPU cluster will enable the observation of the full L-band bandwidth (500 MHz). Further ahead, we plan to install pulsar timing and searching capabilities with the ROACH2 backends (7 ROACH2 and GPUs), in other words SRT's "SARDARA" setup (Melis et al. 2018), which in turn is an integral part of the SERENDIP VI setup. Therefore the instruments used for pulsar timing and searching will be fully integrated within the SERENDIP VI setup.

4. Fast Radio Bursts

Discovered by Duncan Lorimer in 2007, FRBs are astrophysical transients that emit short bursts of radio waves with a duration of just a few milliseconds. They appear as single pulse signals in radio waves, and can sometimes be repeating or periodic. The signals are highly dispersed because of the effects of the interstellar medium, which need to be taken into account. The origin of FRBs is still unknown: could they be stellar phenomena or artificial signals?

4.1. Pulsar and FRB searches with BL data

Our scientific team is collaborating with the BL project for the development of pulsar and FRB search pipelines. The next step will be to test these pipelines on BL data. The goal that once SERENDIP VI is fully set up at SRT, we will have pipelines ready for SETI, pulsars, and FRB searches.

4.2. FRB searches with the KLT

A. Trois & M. Pilia have proposed to search for FRBs using GPU technology and the KLT method. Their project was funded by the Sardinia region. This is an extension of Alessio Magro's work (Magro 2013) on real-time GPU backends, adding on the KLT method (Melis et al. 2016). The project is about the development of software tools for the study of transients such as FRBs using the KLT method; aside from FRBs, it is also applicable to the search for transients such as SETI. It will involve a GPU implementation and machine learning; the implementation of KLT on GPUs; an optimized de-dedispersion algorithm for GPUs; candidate searching via machine learning. The KLT will allow the team to detect weaker signals (both FRBs and SETI), while the reduc-

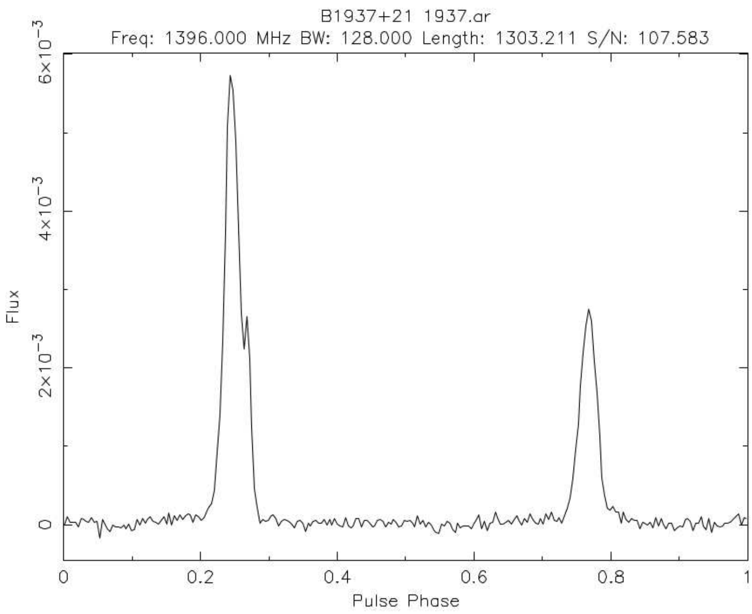

Fig. 1. SRT timing observation of the millisecond pulsar B1937+21

tion in computing time (thanks to GPUs) will allow for real-time searches.

5. Conclusion

The OAC scientific team is involved in a number of SETI-related activities. The main goal for SETI at SRT is to install the SERENDIP VI setup and search simultaneously for ET, pulsars and Fast Radio Bursts (whether with targeted searches or in piggy-back mode). This involves a technological setup as well as, from the perspective of the scientific team, the preparation and testing of search pipelines. The pipelines can in particular be diversified and optimized using the KLT method (as an alternative to the standard Fast Fourier transform) to allow the detection of weak sources; and GPUs to reduce the computing time. More specifically, the team is currently involved in testing standard SETI detection software on BL data; testing the KLT method on BL data; developing pulsar and FRB search pipelines; testing pulsar and FRB search pipelines on BL data; and software tool development for combined FRB searches and SETI with the KLT method.

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