68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.

IAC-17,A4,1,8,x37664

SETI activities in Sardinia: status and ongoing development

A. Melis[a]*, R. Concu[a], D. Perrodin[a], A. Possenti[a], G. Aresu[a], M. Burgay[a], S. Casu[a], A. Corongiu[a], E. Egron[a], F. Loi[a], S. Loru[a], M. Murgia[a], A. Pellizzoni[a], M. Pilia[a], V. Vacca[a], C. Maccone[b], P. Pari[c], M.I. Lunesu[d], C. Migoni[a], A. Navarrini[a], T. Pisanu[a], A. Trois[a], G. Valente[e]

[a] INAF Osservatorio Astronomico di Cagliari, Via della Scienza 5, Selargius (CA), Italy

[b] INAF IASF Milano, Via Alfonso Corti 12, Milano (MI), Italy

[c] INAF IRA Bologna, Via Gobetti 101, Bologna (BO), Italy

[d] DIEE Università di Cagliari, Via Marengo 2, Cagliari (CA), Italy

[e] Agenzia Spaziale Italiana, Via del Politecnico sn, 00133 Roma (RM), Italy

* Corresponding Author

Abstract

The Astronomical Observatory of Cagliari (OAC) is part of the Italian National Institute for Astrophysics (INAF). OAC is located in Sardinia, Italy, an island that hosts one of the largest European single-dish radio telescopes: the 64-m diameter Sardinia Radio Telescope (SRT). After completion of its technical and scientific commissioning, a six-month early-science program of regular observations was successfully completed in 2016.

In this paper, we discuss the main SETI activities that are being carried out at INAF-OAC. In particular, we present the various detection algorithms (FFT, KLT, Wavelet) that are under development, and the perspectives for employing a Phased Array Feed for future SETI programs at SRT.

Keywords: KLT, FFT, SETI, SRT, PAF, Wavelet

Acronyms/Abbreviations

- Advanced Instrumentation Program (AIP)
- Breakthrough Listen (BL)
- Fast Fourier Transform (FFT)
- Fast Radio Burst (FRB)
- Field of View (FoV)
- Graphical Processing Unit (GPU)
- Green Bank Telescope (GBT)
- Istituto Nazionale di Astrofisica (INAF)
- Kahrunen-Loève Transform (KLT)
- Low Noise Amplifier (LNA)
- Osservatorio Astronomico di Cagliari (OAC)
- Phased Array Feed (PAF)
- PHased Arrays of Reflector Observing Systems (PHAROS)
- Regione Autonoma della Sardegna (RAS)
- Reconfigurable Open Architecture Computing Hardware (ROACH)
- Radio Frequency over Fiber (RFoF)
- SArdinia Roach2-based Digital Architecture for Radio Astronomy (SARDARA)
- Sardinia Radio Telescope (SRT)
- Search for ExtraTerrestrial Intelligence (SETI)
- Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations (SERENDIP)
- Square Kilometer Array (SKA)
- Signal-to-Noise Ratio (SNR)
- Very Long Baseline Interferometry (VLBI)

1. Introduction

The Sardinia Radio Telescope (SRT, www.srt.inaf.it), a challenging scientific project of the Italian National Institute for Astrophysics (INAF), is a new, general-purpose, fully-steerable, 64-m diameter radio telescope designed to operate with high efficiency across the 0.3-116 GHz frequency range. The telescope is located on the Sardinia island, Italy, at a short distance (35 km) from the Astronomical Observatory of Cagliari (OAC),

which hosts the general headquarters for astrophysics research in Sardinia, where the telescope instrumentation is developed in collaboration with other INAF partner institutes. An early science program was completed with the SRT in August 2016 following the successful technical [1] and scientific [2] commissioning of the telescope and its instrumentation. The SRT antenna can be operated as a single dish, or as part of the VLBI network, and is designed to perform radio astronomy science, geo-dynamic studies, Deep Space Network (DSN) and space-debris activities. In addition, the SRT can be used to conduct the search for life in the Universe, and play an active part in SETI programs: a number of OAC staff members are interested in SETI, both for technological and scientific activities. In particular, next-generation receivers are already being considered for possible SETI purposes, such as the Phased Array Feed (PAF) technology, which is currently under development in the framework of the SKA Advanced Instrumentation Program (AIP).
In this paper, we present an overview of the aforementioned activities, as well as future perspectives, also taking into consideration the fact that SETI activities in Italy are changing and growing.

2. *Technological developments*

The main lines of research concern mathematical algorithms, which are applied to signals acquired by the SRT.

- *Fast Fourier Transform (FFT)*: Up until now, SETI has been conducted around the world by exploiting traditional FFT-based approaches, which makes sense since a monochromatic signal could be the most probable kind of intelligent signal with which another civilization would wish to make itself heard. This is also why the FFT is quite suitable in terms of computational power when compared to other algorithms. In a previous paper [3], we already mentioned the platform with which such research will be done at SRT: it is named SARDARA (SArdinia Roach2-based Digital Architecture for Radio Astronomy); a few papers ([4], [5], [6], [7]) have already been published with data provided by this digital back-end at SRT. One of the projects that are scheduled for SARDARA is the porting of the SERENDIP VI [8] machine, which is currently used at the Green Bank Telescope. Specifically, we will make use of the ROACH2 boards to split the incoming wideband signal into a few sub-bands and exploit high-performance GPUs for the fine (up to one tenth of Hz) channelling. SARDARA is going to be fully installed and operational by the end of this year, and a first set of SETI exploratory tests of data acquisition and processing might take place in 2018. Moreover, as explained in section 3, a simultaneous study of pulsars and Fast Radio Bursts (FRBs) is possible with the help of the astronomical community at OAC.

- *Kahrunen Lòeve Transform (KLT)*: The KLT is a mathematical procedure that is capable of extracting signals with an SNR that is much lower than that of the background cosmic noise. As such, the KLT is superior to the Fast Fourier Transform (FFT) techniques, for which the extraction of weak signals starts failing when SNR<1. This happens because, while the FFT uses only sines and cosines as the set of orthonormal functions by which the signal expansion into an infinite series is achieved, the KLT may use a host of different orthonormal functions (basis functions): Bessel functions, prolate spheroidal functions, Haar functions typical of Wavelets, and so forth. Historically speaking, this makes sense since the Fourier Transform was firstly published by Fourier around 1807 using sines and cosines only as orthonormal basis functions, while all other different base functions were discovered by mathematicians in the two centuries after 1807.

In practice, the KLT discovers which set of basis functions are the eigenfunctions of the autocorrelation of the input stochastic process, i.e. of the input “noise”, buried in which there may or may not be the sinusoidal carrier of an Alien deterministic signal. The KLT is a thus a /statistical/ tool for recovering weak signals out of noise, rather than a deterministic tool like the FFT. In terms of computability, the difficulty with the KLT is that, for N samples of the input, it scales as N*N or worse, while the FFT only scales as N*ln(N). In other words, the FFT is much faster than the KLT, which is why the FFT was preferred to the KLT in the 70 years since its discovery in 1946 by the Finnish actuary, Kari Karhunen (1915-1992) and the French-American mathematician Michel Loève (1907-1979). If time is regarded as a continuous variable, as in classical physics, then you must first know an analytical expression for the input noise (such as the autocorrelation of the Brownian motion if the input noise is Gaussian) and then, analytically, you must solve the integral equation having such an autocorrelation as its kernel. This integral equation is what, in the language of quantum physics, is called “eigenvalue equation for the autocorrelation of the input stochastic process” and so, in loose terms, one might also say that “the KLT is the Hilbert space mathematical apparatus typical of quantum physics but applied here to signal processing”. Clearly, if the time is discrete, as always happens in digital computers, the above integral equation becomes a system of simultaneous linear algebraic equations, whose solution may require a long time, like N*N. In SETI research, the KLT was first recognized as an important innovative algorithm for detecting an Alien signal by François Biraud at Nançay (in France) in 1983 and, independently, by Bob Dixon in the USA in the mid 1980s, and, independently again, by Claudio Maccone in Italy in 1987. The mathematical treatment of the KLT is amply presented in [3], where its CPU-GPU implementation is explained as well. In essence, the goal is to get the axes describing the acquired signals (for instance by a large radio telescope) in the best possible way; in order to do so, we calculate the eigenvectors/eigenvalues of the autocorrelation matrix of these signals. Once we obtain both these eigenvalues and eigenvectors, SETI experts can then pursue a specific analysis of these values to determine whether the sinusoidal carrier of an Alien signal is embedded or not in the received noise.

A first implementation of the KLT at SRT is described in [3], and a further optimization is under development. In this regard, we are collaborating with UC Berkeley and in particular with Greg Hellbourg; about once a month there is a meeting Italy-Berkeley with discussion about the KLT from several points of view: the common goal is to study all possible solutions for finding intelligence in the signal collected by telescopes involved in SETI.

- *Wavelet*: Wavelets have proven to be a powerful mathematical tool in digital signal processing. Many astrophysical signals display a period behaviour, characterized by a well-defined localization in the frequency domain. In fact, the traditional FFT-based technique is very effective in revealing signals at a particular frequency. However, many real-world sources show time variation in frequency and amplitude, which can be difficult to catch and analyse with the standard FFT approach. In contrast, wavelets are localized both in frequency and in time and thus are able to deal with non-stationary signals. While it is reasonable to assume the intentionally emitted SETI signal could be monochromatic, we should also be prepared to the fact that unintentional signals could not be constant in frequency and amplitude. Indeed, wavelets are very useful to deal with features like sharp transients or frequency changes. We successfully employed the wavelet analysis to separate the true sky signal from the scanning noise in the context of the imaging of spectral polarimetric SRT data acquired with the SARDARA back-end (see [4]). We are now considering developing these Wavelet-based techniques as an alternative tool for processing data collected in the context of SETI activities.

3. *Scientific activities*

Before SRT starts to collect data for SETI (either in piggy-back mode or with dedicated time), the scientific team at OAC will gain experience on analysing SETI data. This will first involve the analysis of GPU baseband data using known SETI software. In particular, thanks a collaboration with the Breakthrough Listen (BL) program, the team will test BL's GPU software spectroscopy suite on BL baseband data. Subsequently, the scientific team will test the KLT algorithm on the same type of data.

An important aspect is the possibility to conduct search of extraterrestrial intelligence, and use SETI data also for astrophysical science, like search of pulsars and Fast Radio Bursts (FRB). The OAC has a strong team of pulsar/FRB scientists; their expertise in pulsar science will enable the team to collaborate with BL on the building of pulsar and FRB search pipelines, as well as test these pipelines on BL baseband data.

Finally, when SERENDIP VI will have been installed in SRT, pipelines ready for SETI searches, as well as pulsar and FRB searches, will become available.

4. *Future of SETI in Sardinia: Phased Array Feeds*

Phased Array Feeds are an enabling technology for a new generation of radio telescopes. In contrast to a single feed or to multi feeds (cluster of feeds), the elements of a PAF are closely spaced and combined in weighted sums to make multiple independent beams. These beams are processed simultaneously. In particular, a phased array feed is a multi-beam receiver that can adapt to the optics of any radio telescope by synthesizing multiple, simultaneous beams on the sky for complete coverage of the available field of view (FoV), without loss of sensitivity in each beam. As a result, the survey speed figure of merit of a radio telescope equipped with a PAF is expected to increase drastically with respect to that obtainable with more conventional single-feed or multi feeds, which cannot fully sample the focal plane and require few interleaved pointings to fully sample the sky. In addition to an increased survey speed, PAF technology allows the following improvements compared to the traditional multi feed systems: a) increased antenna efficiency; b) broader bandwidth; c) improved radiation pattern; d) correction of reflector surface defects; e) reduction of baseline ripple; f) interference cancellation; g) improved polarization purity. In addition, the PAF technology may enable to electronically steer a subset of the synthesized beams towards specific directions of the sky (inside the FoV) so that they can be used for SETI application, while the remaining synthesized beams can be oriented toward other directions, for example, radio astronomy sources. Additionally, one of the beams can be used for calibration purposes, without requiring to continuously move the antenna back and forth from sources to calibrators, thus improving the observing efficiency. Thus, PAFs are flexible instruments that can be used to conduct simultaneous research in radio astronomy science and SETI observations.

The INAF OAC team, in collaboration with national and international institution, is contributing to the development of PHAROS, (PHased Arrays for Reflector Observing Systems), a C-band cryogenically-cooled low-noise PAF developed as part of a European technology demonstrator project cooperated by an international collaboration that includes the INAF OAC. The PAF consists of 220 elements Vivaldi array (Fig. 1) cooled to 20K along with 24 low noise amplifiers (LNAs) mounted directly behind the antennas. The LNAs are followed by low-loss low thermal conduction RF connections to the analog beam forming system designed to operate at 77 K.

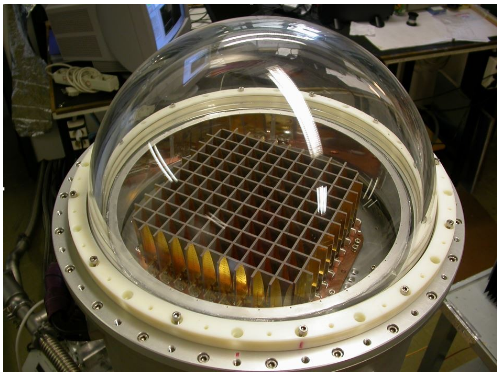

Fig. 1: View of PHAROS Vivaldi antenna array and dome-shaped Plexiglas vacuum-window.

In the framework of the PAF Advanced Instrumentation Program for SKA, we are upgrading PHAROS [9] to a new instrument named PHAROS2 [10]. PHAROS2 is a technology development program towards SKA Phase2 to demonstrate feasibility and competitiveness of high-frequency PAF technology. The instrument will be mounted on large European single-dishes to perform radio astronomy observation across the 4-8 GHz range. PHAROS2 will be a cryogenically-cooled C-band PAF demonstrator with a down-conversion system, Radio Frequency over Fiber (RFoF) analog signal transportation and digital beamformer capable of forming 4 independent beams using 24 active elements. The architecture of the beamforming is chosen to allow rescaling to a much larger number of beams and bandwidth.

5. *Conclusions*

We have outlined the various activities that are currently being implemented at INAF-OAC in the framework of the SRT project. After a major revision of its active surface, the SRT telescope is being re-commissioned and will be ready to collect data suitable for radio astronomy and SETI within a year. SETI activities can be performed in piggy-back mode with the SARDARA backend. Three algorithms will be applied on the raw data: FFT (SERENDIP VI), KLT and Wavelet. At the same time, the OAC personnel that is interested in contributing to the SETI activities is growing. Pulsars, FRBs and SETI observations can be run in parallel; pending availability of data taken by SRT, scientists are going to get acquainted with the data provided by the Parkes and Green Bank telescopes, in the context of the BL program. Finally, our team has started development of a Phased Array Feed demonstrator named PHAROS2 in the framework of a European collaboration. The PAF technology represents the future of radio astronomy and is being considered for use at SRT. The SETI program could have great benefits if SRT were equipped with a PAF: in addition to SETI observations in piggy-back mode with the "radio astronomy PAF beams", we could reserve one or more PAF beams to conduct dedicated SETI search and observe selected areas of the sky in the direction of potentially habitable planets, thus significantly increasing the SETI observing capabilities.

Acknowledgements

A special thanks to the Autonomous Region of Sardinia (RAS) [11] that has funded the project named "High resolution sampling of the Universe in the radio band: an unprecedented instrument to understand the fundamental laws of nature" - P. I. of the project Andrea Possenti - in the context of the research project CRP-49231 (year 2011). This financing allows the development of the SARDARA platform.

References

[1] P. Bolli et al. "Sardinia Radio Telescope: General Description, Technical Commissioning and First Light" Journal of Astronomical Instrumentation, Vol. 4, Nos. 3 & 4 (2015) 1550008 (20 pages).

[2] I. Prandoni et al. "The Sardinia Radio Telescope: from a Technological Project to a Radio Observatory", 2017, arXiv:1703.09673.

[3] A. Melis et al. "A real-time FFT-KLT implementation for SETI research at the Sardinia Radio Telescope", IAC-16,A4,1,8,x34113

[4] M. Murgia et al. "Sardinia Radio Telescope wide-band spectral polarimetric observations of the galaxy cluster 3C129, MNRAS, Volume 461, Issue 4, p. 3516-3532, 2016).

[5] F. Govoni et al. “Sardinia Radio Telescope observations of Abell 194: the intra-cluster magnetic field power spectrum”, A&A, 2017, 603, A122).

[6] E. Egron et al. “Imaging of SNR IC443 and W44 with the Sardinia Radio Telescope at 1.5 GHz and 7 GHz”, MNRAS, Volume 470, Issue 2, p. 1329-1341, 2017.

[7] F. Loi et al. “Observations of the galaxy cluster CIZA J2242+5301 with the Sardinia Radio Telescope”, MNRAS, 2017, arXiv:1708.07125

[8] https://casper.berkeley.edu/wiki/SETI/

[9] L. Liu, K. Grainge, A. Navarrini "Analysis of Vivaldi array antenna for phased array feeds application," International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization for RF, Microwave, and Terahertz Applications (NEMO), 2017 IEEE MTT-S, Sevilla, Spain, 17-19 May 2017.

[10] http://www.astron.nl/ska-aip2017/Documents/Friday/SKA-AIP_Navarrini.pdf

[11] http://www.regione.sardegna.it/