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The Horizon Europe project Radioblocks and its impact for the EVN

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Abstract. Radioblocks is a European Commission-funded project that aims to go beyond state-of-the-art technological solutions to increase the sensitivity, field of view and bandwidth of radio astronomy infrastructures. Although these developments address aspects for almost all radio astronomical infrastructures along the entire data chain, VLBI will specifically benefit from their results and deliverables. Radioblocks is divided into tasks that work on different parts of the signal chain. One task is dedicated to Novel Detectors and Components to address the developments of improved cryogenic LNAs and SiS mixers, among others. This will allow large bandwidths and simultaneous observations at different, largely separated frequencies to study the emission of sources at increased sensitivity. The Digital Receivers task will develop and demonstrate receivers that produce large data streams capable of RFI mitigation, including cryoPAFs and a prototype VLBI backend that will allow broadband and multi-frequency observations. Data Transport and Correlation is another important part of the signal chain: one task is therefore dedicated to processing the data produced by the new receiver systems. It will develop a collection of efficient, high-performance signal processing blocks using commercially available hardware accelerator platforms such as FPGAs, tensor core-enabled GPUs for correlations, and off-the-shelf Ethernet network switches for high-speed data transfer. The last block of the signal chain deals with the implementation of a generic Data Processing Tool Kit to handle the post-processing of large data streams. This includes fringe fitting, advanced data processing algorithms to handle data with sparse visibility and simulations to extend the EHT tools for cm-VLBI or study different SKA-VLBI observing scenarios.

1. Introduction

Radio astronomy is crucial to building a comprehensive picture that links the early history of the Universe to the formation of the first stars and galaxies, the development of galaxy clusters and the cosmic web, the formation of proto-stars and planets, and the conditions for life. Radio telescopes have been key in the development of astrophysics and cosmology by revealing novel aspects of the Universe that cannot be studied in any other way. In recent years, the capabilities of radio telescopes have been expanded by developments in electronics and data processing, taking advantage of progress in computing and telecommunications, but also producing innovations and new techniques. The project *"New science in Radio Astronomy: applying cutting-edge technology to enhance the entire data chain, from receiver to final output"*, or **Radioblocks**, takes a holistic view of how radio telescope arrays capture, process, synthesize and analyze cosmic signals. Radioblocks is a four-year project, started in March 2023, funded by the European Union's Horizon Europe research and innovation programme (grant agreement number 101093934) to generate components, technologies and software, applicable to a wide range of radio astronomical instruments.

The Radioblocks consortium is coordinated by the Joint Institute for VLBI ERIC (JIVE) and it consists of 34 partners from 13 countries, including two intergovernmental organizations, ESO and SKAO. These partners join forces to develop "common building blocks" for technological solutions beyond the state-of-the-art, that will enable a broad range of new science and enhance European scientific competitiveness. These improvements will not only benefit existing facilities but also contribute to the development of future instruments like the Square Kilometer Array (SKA).

Radioblocks is designed to have a lasting impact on the scientific capabilities, efficiency, flexibility, and usability of Europe's most powerful radio astronomy facilities. To maximise its impact, Radioblocks addresses all stages of the signal and data flow, from the point at which radio signals are first intercepted at the antennas to the final production of science-ready data-cubes. By adopting a 'building block' approach, the developments can be used in a wide range of facilities.

Substantial parts of the work are done as academic-industry collaborations at national and local levels. At the same time, Radioblocks uses newly available commercial hardware for novel radio astronomical applications, developing its performance and extending its range in new directions. The societal impact of innovations pioneered by radio astronomers is well-known. By expanding the capabilities of a wide range of leading radio astronomy instruments, Radioblocks expects to make its contribution to wider cultural impacts.

2. Objectives

The objective of Radioblocks is the development of common building blocks for:

- multipixel Phased Array Feed/Focal Plane Array (PAF/FPA) receivers, ranging from cm to submm wavelengths, suitable for large single-dish facilities, with special relevance for future collaborations with pan-European and global infrastructures (e.g. SKA-VLBI);

- cutting-edge frontend technologies, addressing the generation and real-time handling of wide band and multi-band data, in particular for the creation of novel detectors and components, both RF and IF, as well as the design of backends, with built-in RFI mitigation;

- the next-generation correlators, which can efficiently exploit extremely powerful new commercially available accelerator hardware (GPUs);

- the implementation of a generic software toolkit to handle the post-processing of the resulting (very) large data streams, to be used for the creation of specialised pipelines, including the application of RFI mitigation techniques and the use of advanced data-processing algorithms.

An additional objective is to strengthen the foundation for collaborations on radio astronomy instrumentation. Bringing experts in the radio astronomy community together in so many different disciplines, covering many different frequencies and various parts of the signal chain, is a huge investment in the current and future European technological innovation.

Radioblocks is divided into work packages to develop these core objectives.

2.1. WP1 - Management

WP1 deals with the managerial duties of the project. It consists of JIVE personnel and includes the coordinator, the project manager, the financial officer, the communications officer, and a project officer. Besides assisting the other WPs with their activities WP1 oversees the implementation of the project plan. A crucial deliverable of WP1 is the establishment and coordination of an external industrial advisory board that advise the project on how to raise awareness inside and outside the field of radio astronomy, both within scientific and industrial communities

2.2. WP2 - Novel Detectors and Components

WP2 is dedicated to designing and developing advanced components to be integrated into the future generations of receivers for European radio astronomy observatories. WP2 primarily focuses on:

- **RF Windows, Lenses, and Filters:** Developing novel lens technologies, such as meta-lenses, to improve signal focusing and enhance receiver sensitivity.
- **Orthomode Transducers (OMTs):** Designing and production of high-performance OMTs, which further contribute to higher sensitivity.
- **Horns:** Optimizing horn antenna designs to improve signal coupling and minimize signal loss.
- **SIS Mixers:** Developing next-generation superconducting tunnel junction (SIS) mixers, essential for achieving high sensitivity at millimeter and submillimeter wavelengths.
- **Low Noise Amplifiers (LNAs):** Building low-noise amplifiers with wider bandwidths and improved noise characteristics.
- **Local Oscillators (LOs):** Developing high-frequency and high-power local oscillators.
- **Tuneable Filters:** Building tunable filters capable of suppressing radio frequency interferences (RFI).

2.3. WP3 - Digital Receivers

WP3 bridges the analog and digital receiver technology, focusing on improving system temperature, expanding bandwidth, and increasing field-of-view. To achieve these goals, WP3 works on:

- **Developing a "European Technology Toolbox":** Creating technological solutions that can be readily adopted and adapted by a diverse range of radio astronomy instruments across Europe.
- **Novel Beamforming Technology:** Developing and demonstrating novel beamforming techniques, using RF System-on-a-Chip (RFSoC) technology to enhance the capabilities of Phased Array Feeds.
- **PAF-RFI Mitigation and Adaptive Beamforming:** Implementing robust RFI mitigation strategies specifically tailored for PAFs.
- **Next-Generation VLBI Backend Demonstrator:** Developing and demonstrating the next-generation VLBI backend system.

– **Multipixel Astronomy via Focal Plane Arrays:** Advancing multipixel radio astronomy with the use of focal plane arrays.

2.4. WP4 - Data Transport and Correlation

WP4 is dedicated to developing high-performance, scalable signal processing building blocks for next-generation correlators. In particular:

– **Developing and Implementing GPU-Based Correlator Building Blocks:** Creating and integrating efficient, reusable GPU-accelerated signal processing modules, based on Tensor Core technology, for future correlator systems.
– **Exploring and Implementing High-Speed Data Transport Technologies:** Investigating and demonstrating high-speed data transport solutions, such as DPDK and RDMA.

2.5. WP5 - Data Processing Tool Kit

WP5 develops a versatile toolkit of open-source software designed to streamline data processing pipelines. WP5 dedicates its effort on:

– **DASK-Based Workflow Automation:** Using DASK, a parallel computing Python library, for optimizing automated processing workflows, improving efficiency, and enabling the handling of large datasets.
– **Generic Fringe-Fit Calibration Tool:** Developing a scalable fringe-fit calibration using parallelization in the DASK framework.
– **Simulations for Optimizing VLBI Data Analysis:** Using simulations to explore strategies for optimizing calibration and parameter extraction from VLBI data.
– **Bayesian Inference Techniques for Sparse VLBI Data:** Investigating and developing Bayesian inference methods for the analysis of sparse VLBI datasets.
– **Modular Processing Toolkits for Phased Array Feed Backends:** Creating modular, scalable backend processing systems for PAFs, promoting flexibility, adaptability, and code reuse across different radio astronomy instruments.

3. Results

In its first year, the Radioblocks project demonstrated excellent progress towards achieving its objectives.

The design work for common building block prototypes began, focusing on generating wideband data for novel Focal Plane Array receivers, both at radio frequencies and at intermediate frequencies. Much effort was devoted to work optimization as preparation for actual prototyping. The overall activity was divided into several tasks addressing individual components along the signal chain, from optical elements like lenses to SIS mixers, LNAs, local oscillators, and a W-band down-converter.

Moreover, the framework for a European technology toolbox was established. This toolbox will allow astronomers to adapt and adopt technology solutions for a wide range of instruments, from small and large single-dish telescopes to continental and global homogeneous and heterogeneous dish arrays. Key software tools were developed, while the design and prototyping of appropriate broadband hardware were initiated.

The creation of the first common building blocks for the development of new correlators has started. The next-generation correlators can efficiently exploit powerful new commercially available accelerator hardware (such as GPUs). The different building blocks are being developed to fit the specific use cases that the Research Infrastructures involved (EVN + eMERLIN/JIV-ERIC, LOFAR/ILT, ALMA/IRAM) need to tackle while paying attention to their generalization, when possible, and reusability.

Automated processing workflows were investigated. Additionally, the development of a generic and scalable fringe fit calibration implementation has started. An inventory of the different software packages available to generate synthetic data for radio interferometry over long baselines was initiated, as was the work of building a framework for the development of modular subsystems for PAF processing.

4. Impact

Radioblocks is already having a profound impact on radio astronomical instrumentation. Individual components for the analog part of the signal chain were investigated, simulated, and started to be manufactured.

An example of how Radioblocks developments can impact the community is the work on providing increased, simultaneous spectral coverage needed for studies of interstellar chemistry. Another example is the collaborative effort to build a compact downconverter of the 67-116 GHz RF band, which is one step towards possible large focal plane arrays for wide-field imaging.

Work in data transport and correlation addressed directly the objective of enhancing the scientific competitiveness of European research infrastructures, focusing on the development of the building blocks for (GPU-based) correlator and beam-former applications that can be generalized and re-used later by other research infrastructures, increasing competitiveness of the facilities involved in Radioblocks.

Radioblocks is working to demonstrate GPU signal processing at 400 Gb/s Ethernet input data rates within the radio astronomical community, while the integrated GPU/network approach brings us to the forefront of High-Performance Computing science in general. One application of cutting-edge accelerator hardware technology has been made available to Radioblocks partners, and more are in development.

Regarding the digital part of the signal chain, progress towards impact can be seen in the Cryo-PAF hardware developments, which have come to fruition when combined with the accelerated post-processing done on state-of-the-art commercial off-the-shelf hardware. This is a gigantic step forward in the field-of-view of the telescope where the system will be mounted.

Several European infrastructures invest in new or upgraded hardware to increase the sensitivity, field-of-view, or both, of existing (big) radio telescopes or arrays. With that comes an increase in data volume which needs to be post-processed promptly. Being at the forefront of exploring technologies, such as Python DASK, brings European researchers and scientists in a position to be asked to collaborate on projects inside and outside of Europe. This is witnessed by a number of requests to join the Radioblocks project from non-EU institutions.

5. Conclusions

Research in the fields of astronomy, cosmology and fundamental physics is important for building international competitiveness and creating technology. The activities of Radioblocks aim to enhance the potential of the most advanced radio astronomy facilities within Europe with a particular focus on three areas.

Scientific: Radioblocks has already started to deliver major improvements to the scientific capabilities of a wide range of large-scale world-class radio astronomy research infrastructures. At the end of the project, enhanced European research facilities will take advantage of Radioblocks 'building blocks' paving the way to new scientific discoveries.

Technological/Economic: While Radioblocks targets radio astronomical research infrastructures, its work is done together with a range of hi-tech companies. At its core, Radioblocks includes elements to produce new technologies and explores new directions of commercial technologies fostering collaborations between partners.

Societal: The impacts of astronomy extend beyond research into wider cultural areas. Understanding our place in the cosmos is of fundamental importance to humanity. Over the last 60 years, radio astronomy has expanded and transformed our view of the universe: the radio sky is radically different to what our eyes see. Radioblocks wants to enable radio astronomers to make the next discoveries and expand our knowledge of the Universe.

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