The Yebes Observatory and the Future VLBI Correlator for the RAEGE Network

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Abstract This paper describes the geodetic VLBI activities carried out at the Yebes Observatory and gives an update about the status of the RAEGE project. The design of a VLBI correlator for the RAEGE network has just started based on the experience gained with a prototype that is installed on site. The development of the correlator is part of the YNART project, co-funded with ERDF 2014–2020 funds, granted by the former Spanish Ministry of Economy, Industry, and Competitiveness.

Keywords Radio astronomy, space geodesy, global astrometry, VLBI technique, software correlator

1 Yebes Observatory and the RAEGE Project

The Yebes Observatory is a Spanish singular scientific and technical infrastructure, the only one located in the Castilla–La Mancha autonomous region, dedicated to astronomy and astrophysics and the study of the Earth through space-geodetic techniques. The observatory is strategically placed on the European tectonic plate, in the center of the Iberian Peninsula, 80 km from Madrid. Our 40-m diameter antenna, the only fully Spanish radio telescope, is a world reference in chemical studies of the interstellar medium [1, 2, 3, 4], and it participates in astronomical, geodetic, and global astrometric VLBI observations in collaboration with the main networks (e.g., EVN, GMVA, IVS). The RAEGE 13.2-m diameter VGOS-type antenna participates regularly in the VGOS and EU-VGOS observing programs and in other R&D campaigns. Apart from VLBI, the GNSS space-geodesy technique is also present at the observatory—in addition to a gravimetry laboratory, a local tie network, a time and frequency system, and other facilities. Thanks to the Spanish-Portuguese RAEGE Project (Atlantic Network of Geodynamical and Space Stations) and the European Regional Development Fund (ERDF), the observatory will soon become the first fundamental geodetic station in Spain, with the forthcoming addition of a Satellite Laser Ranging station. When completed, the RAEGE network (Figure 1) will consist of four fundamental geodetic stations located on the

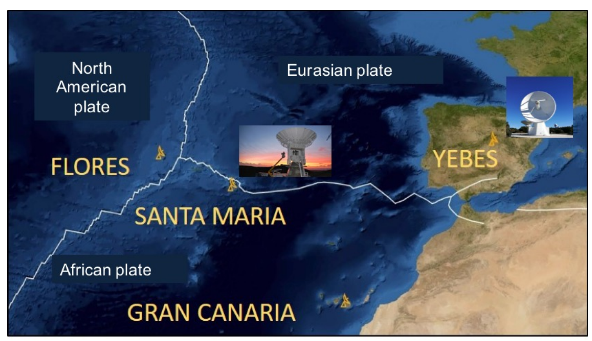

Fig. 1 The RAEGE network, comprised of four sites from the Azores Islands (two sites) to the Canary Islands to Yebes Observatory on the Iberian Peninsula, will study in detail the interaction between the North American, the Eurasian, and the African tectonic plates.

Azores Islands (two sites), Canary Islands (one site), and Yebes (one site), each equipped with a 13.2-m radio telescope with VGOS specifications, gravimeters, and at least one permanent GNSS station. All

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these will be complemented with the Satellite Laser Ranging station at the Yebes site [5]. For the RAEGE network to operate autonomously, the YNART project (Infrastructures for updating the radio telescopes at Yebes Observatory) is providing a scalable and flexible software VLBI correlator.

2 Yebes Core Site Update

Currently there is a busy agenda at Yebes Observatory devoted to the development, testing, and installation of completing the VGOS-type receivers designed entirely by our engineers. A total of three broadband 2–14 GHz receivers will be completed by the end of 2022, for observatories such as Matera, HartRAO, and NARIT, and both Yebes and Santa María VGOS receivers will be upgraded according to [6].

The triband receiver currently installed at Santa María (Azores) will be replaced by the upgraded VGOS one by the end of 2022, and the triband receiver installed in Ny-Ålesund Observatory (NMA) will be replaced by the upgraded VGOS NMA1 receiver sometime during 2023 (the upgraded NMA2 VGOS receiver was installed in late 2021).

Additionally, a new phase calibration module [7] and superconducting filters are under development to improve geodetic receiver performance and avoid radio frequency interferences.

With the addition of the Satellite Laser Ranging station, the YLARA station (Figure 2), the Yebes core site will soon become the first Spanish fundamental geodetic station, with more than three space-geodetic techniques co-located at the same site: VLBI, GNSS, and SLR, together with a gravimetry pavilion and a local tie network of geodetic vertices.

The YLARA SLR station will allow ranging measurements of satellites equipped with retro-reflectors, located at distances ranging from 200 to 42,000 km, and space awareness applications. It will use a pulsed solid state laser on a biaxial telescope with alt-azimuth mount. The SLR civil works for the dome building were already initiated, with solid state laser and detector package commissioning activities to be performed soon at IWF facilities in Graz, Austria.

Fig. 2 Illustration of future YLARA Satellite Laser Ranging station at Yebes Observatory (design by Felipe A. Paredes, Yebes Observatory).

3 Future RAEGE VLBI Correlator

The RAEGE correlator is meant to be used for astronomical and geodetic applications of the RAEGE network. Designed to be an efficient correlator for a four-station network, its main specifications are the following:

- DiFX software correlator [8] running on an HPC.
- Correlator components: four computing nodes with 32 cores per node. Mass-storage with more than 1.5 PB managed under a BeeGFS distributed file system. The connection to the Internet is realized with a 100-Gbps line to the Spanish Research and Education network (RedIris), while Infiniband is the technology chosen to interconnect the nodes in the HPC to reduce latency.
- The initial design is sized to support a minimum of four stations, but it is scalable to support the correlation of larger networks such as EU-VGOS or VGOS.
- Integration of PolConvert [9] and TEC corrections to support antennas with linear and circular polarizations.

- HOPS [10] post-processing pipeline for geodetic applications.
- Flexible to support different VDIF data formats and easily upgradable.
- Support ‘peta’ level rates of floating point operations per second (PFLOPS).
- Support a minimum of four stations with a 32-Gbps data rate per station, observing two days per week.
- Appropriate thermal conditioning of the correlator room.

A 20-month service contract was awarded to the Spanish company QUASAR SCIENCE RESOURCES S.L., with the responsibility to perform a technological study, COTS selection and design of the correlator (in Phase 1), installation (in Phase 2), and commissioning and early operations (in Phase 3), with the schedule detailed in Figure 3.

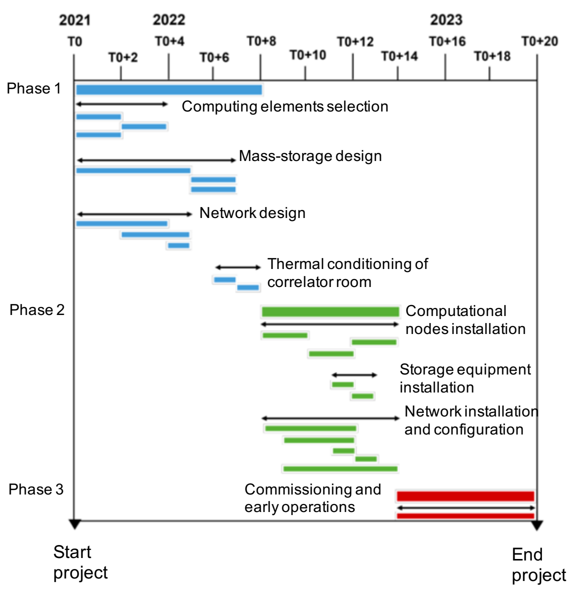

Fig. 3 RAEGE VLBI correlator project schedule.

Prototyping activities for the correlator were already initiated in Yebes, with the assembly of a VLBI DiFX software correlator [8] running on a distributed cluster with a 10 GE private network. This prototype is currently supporting ongoing correlation of EU-VGOS experiments and other local projects.

Additional prototyping activities carried out in the observatory compared CPU versus GPU performance in calculating Fast Fourier Transforms (FFT). The testbed used CUDA to export DiFX routines to parallelized GPU computing. Real VGOS data was applied to the modified DiFX version. It was found that the GPU performance is better than the CPU for increasing the number of points per vector (Figure 4, [11]).

There is a parallel effort at Yebes Observatory to develop a calibration server that contributes with an improved calibration for VGOS telescopes in the network with linear and circular polarizations and to correct for extended source structure.

4 Conclusions

The outcomes of the YNART project will contribute to position Yebes Observatory as the first fundamental geodetic station in Spain, by means of providing a versatile software correlator that supports the different scientific applications of the RAEGE network and that contributes to the correlation efforts of the VGOS and EU-VGOS projects.

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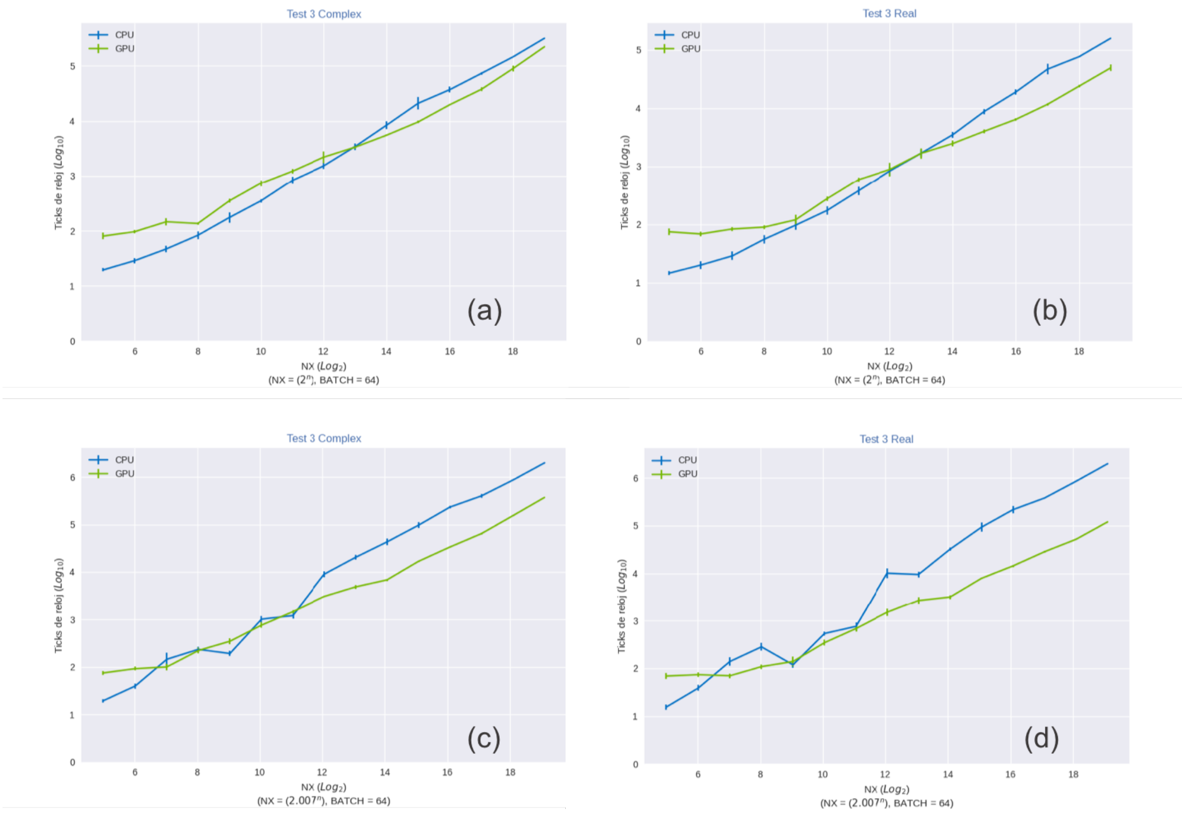

Fig. 4 FFT performance (tick clocks) comparison between a CPU Intel IPP (blue) and a GPU (green) increasing the number of points per vector (NX) for a complex (a,c) and a real (b,d) input and power of 2 number of points (a,b) or not (c,d).

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