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The Einstein Telescope: status of the project

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Abstract. After the groundbreaking first detection of Gravitational Waves by the LIGO/Virgo Collaborations, the design of the third generation of gravitation wave interferometric antennas has gained a substantial interest and momentum. The Cosmic Explorer in the US and the European Einstein Telescope (ET) are the instruments which will take the legacy of the current generation and further advance the reach of the GW antennas, both in terms of explored Universe and of type of accessible sources. The talk focused on the status of the design of the Einstein Telescope, its technical challenges and the expected implications to the Gravitational Wave Astronomy progress.
The paper reflects the content and the status of the ET project at the time of the talk given at RICAP22.

1 Introduction

A new Era in the observation of the Universe was opened by the first historical detection of a Gravitational Wave (GW) signal by second generation (2G) interferometric antennas [1]. Furthermore, the dawn of the Multimessenger Astronomy broke when the GW signal from a binary Neutron Star (BNS) cohalescence was detected, with the subsequent observation of an electromagnetic counterpart [2] in the region of sky pinpointed by the LIGO-Virgo detectors. Many other detections took place in the first three observation runs of the 2G detectors, with a large impact in both Astrophysics and Fundamental Physics, and more science advance is expected for the next observation runs of the current generation.
Nevertheless, such a huge success has to be considered just the first step in the observation of the Universe with GWs. Indeed, third-generation (3G) GW detectors, such as the Einstein Telescope (ET) [3] are already following the path from conceptual design to realization, and will allow the full realization of the potential of the GW Astronomy revolution, thanks to an order of magnitude better sensitivity and a wider accessible frequency band with respect to 2G detectors.
The interest for this next generation detectors has gained of course interest and momentum following the successful outcome of the 2G antennas, but the visionary path for their realization started long before the historical first GW detection [4], a path which brought to the current funding of the ET project and the creation of the ET collaboration at 2022 summer ET symposium, now counting more than 1200 members in 80 research units spread across Europe and Asia.

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2 The Einstein Telescope in a nutshell

2.1 The Observatory

The Einstein Telescope is meant to be not only a 3G detector but a real GW observatory. It will consist in a new underground (−100 m) infrastructure capable to host future upgrades for decades without limiting the observation capabilities. The sensitivity of the detector is aimed to be at least 10 times better than the nominal 2G detectors on a large fraction of the detection frequency band. Moreover, the design will implement a dramatic improvement in sensitivity in the low frequency range (1 Hz to 10 Hz). The infrastructure shall provide high reliability and improved observation capability, including GW polarization disentanglement.

2.2 ET science case

The ET science will span Astrophysics, Fundamental Physics and Cosmology as well. Accessible topics where ET will contribute include the study of Black Hole properties, their origin (stellar vs. primordial), evolution, demography. The same for the Neutron Star properties: it will be possible to study their interior structure (QCD at ultra-high densities, exotic states of matter), and demography. Moreover, the Einstein Telescope will greatly enhance the possibility of Multi-band and multi-messenger Astronomy, for instance by increasing joint GW/EM observations (e.g. GRB, kilonova, etc.). Detections of GW emission coming new astrophysical sources, such as core-collapse supernovae or isolated neutron stars will also become much more likely. The contributions of ET will span also fundamental Physics and Cosmology: it will allow investigations on dark energy equation of state, modified GW propagation, Stochastic backgrounds of cosmological origin and much more [5].

Some are just an evolution of what can be done with the 2G detectors, but ET sensitivity will provide insight in very extreme events with a high signal-to-noise ratio (SNR), and improve the multimessenger ability of the current detectors. In particular, the contribution of ET will be twofold: it will be a discovery machine on one side, because ET will explore almost the entire Universe listening the GWs emitted by black holes back to the dark ages after the Big Bang; and a precision measurement observatory on the other side, since ET will detect, with high SNR, hundreds of thousands of coalescences of binary systems of Neutron Stars per year, revealing the most intimate structure of the nuclear matter in their nuclei.

2.3 ET design and technological challenges

Unsurprisingly, in order to realize these challenging science goals, very tight requirements and design specifications are needed, which translates in tough technological challenges. ET is requested to operate in a wide frequency range (1 Hz to 10 Hz), to have an unprecedented sensitivity for massive black holes (focus on the low frequency part of the detection bandwidth), localisation capability, (more) Uniform sky coverage, polarisation disentanglement, high duty cycle, and high SNR. These requirements suggested a multi-interferometer design to extend the detection bandwidth (Xylophone), to go underground to provide a more quiet environment, to use cryogenic temperature for the test masses, to employ multi-detectors with different orientations for sky coverage and polarization disentanglement, and to the obvious choice of longer arms (10 Km) to increase the strain sensitivity. The Xylophone approach means that for each of the detectors in the multi-detector scheme, two different interferometers are realized: one more sensitive to the low-frequency band (LF), and the other to the high frequency (HF) region of the detection bandwidth. The requirements for these two interferometers are different and so their technological challenges. For the LF interferometer the thermal noise of coating and suspensions will play a major role, so a cryogenic temperature for the test masses is foreseen. This implies changing the substrate material of the test masses from Fused Silica to Silicon (or Sapphire) and change the wavelength of the laser, with the related new technologies to be developed. Furthermore, new seismic isolation has to be developed to cope with more stringent requirements at low frequency. Instead, the HF interferometer will require very high laser power, and this in turn will pose severe requirements to the ability to control thermal aberrations, just to cite some of the problems to face. A complete and updated technical design can be found in [6].

3 A site for ET

The site where ET will be built will play a non-negligible role for the ultimate performances of the detector in terms of noise. After a wider survey, basically two sites are still valid candidates to host the ET observatory: the Sardinia site, close to the Sos Enattos mine, the Euregio Rhine-Meusse site, close to the Netherland-Belgium-Germany border (a third option in Saxony, Germany, is under discussion). Both sites are undergoing a thorough characterization to determine their possibility to host ET, also in terms of logistics and funding possibilities. The choice of the site is expected to happen at some point during 2024.

3.1 Euregio Meuse-Rhine

In this site a 250 m deep borehole has been excavated and equipped, seismic data are under acquisition and analysis and a set of other boreholes are under excavation. An extensive active and passive site characterisation with sensor arrays was carried on in 2021 showing good seismic noise attenuation given by the particular geological structure. The characterisation funded through Interreg grants, and a large proposal for qualifying the site has been essentially approved by the Dutch government.

3.2 Sos Enattos

The Sardinia site is close to the Sos Enattos mine. A long standing characterization of the mine in one of the corners has started some years ago and is still continuing: seismic, magnetic and acoustic noise characterisations are ongoing at different depth in the mine. Furthermore an underground laboratory (SarGrav) has been recently inaugurated. Two 290 m boreholes have been excavated, equipped and data taking is ongoing, while another set of boreholes is expected in 2022 or beginning of 2023. For this site an intense and international surface investigations program is ongoing, its characterisation is funded on regional and national funds, while a large proposal for technology development and engineering design has been submitted to the Italian government.

Conclusions

The Einstein Telescope is a huge enterprise, with a potentially dramatic increase of GW Scientific revenue. The interest of large community and the actions of a reduced set of scientists pushed it through more than a decade, and in the last few years ET acquired a large momentum and now it is a global scale project: on June 2022 the ET collaboration was estabilished with more than 1200 members from 80 Research Units. The sinergy with the European authorities at government level is being achieved, and funds are arriving. The active collaboration with the other third generation project (the US Cosmic Explorer) is a key factor, but

ET can produce great science also in stand-alone configuration Multi-messenger Astronomy with ET will be greatly enhanced, possibly a prioritazion of triggers will be needed due the big number of GW signals.

References

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