10th Einstein Telescope Symposium

Thursday 11 April 2019 - Friday 12 April 2019

Marina Resort

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Book of Abstracts

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Status of the ET project

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The current activities of the ET project, the process for the formation of the collaboration, the ESFRI proposal activities, the ET roadmap and the worlwide scenario will be presented

ET Science / **27**

ET Science Case

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An overview of the Science Case of Einstein Telescope is presented. The related activities for the preparation of the ET light Technical Design report are discussed

ET Science / **7**

Binary compact objects across cosmic history

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Einstein Telescope will possibly observe mergers of binary black holes (BBHs) and binary neutron stars (BNSs) to redshift z10 and z2, respectively. Thus, we will be able to characterize the evolution of binary compact objects through cosmic history. Here, we show that constraining the merger rate density and mass evolution of BBHs across cosmic time is a powerful tool to shed light on their formation scenarios. We predict the merger rate density of stellar-born BBHs in the comoving framework to increase by a factor of ~10 between redshift 0 and redshift ~3, where we expect it to reach a peak of ~ 500 - 1000 Gpc^{-3} yr^{-1}. This result springs from the dependence of the merger rate from cosmic star formation rate and stellar metallicity. Furthermore, we predict a mild evolution of BBH mass distribution with redshift, if we assume that BBHs form mostly from massive metal-poor stars. We expect a significantly different evolution from scenarios (e.g., primordial black holes) in which the mass of black holes does not depend on the metallicity evolution. Einstein Telescope will probe both the merger rate density and mass evolution, providing constraints on the main paradigms of BBH formation, as well as on the final fate of massive stars across cosmic time.

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Deeper, wide, sharper: binary black holes in the next generation of ground based detectors

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Next-generation GW observations will uncover binary black holes throughout the entire Universe back to the beginning of star formation, and will detect new source types (if they exist) beyond stellar-mass binaries, such as intermediate-mass black holes. A number of key questions can be posed that will find an answer:
1) What is the merger rate as a function of redshift to the beginning of the reionization era, and how does it correlate with massive star formation, metallicity, and galaxy evolution?
2) What are the mass and spin demographics of black holes throughout the Universe, are they correlated, and do they evolve with redshift? What do they reveal about the formation and evolutionary origin of BBHs?
3) Do seeds of supermassive black holes exist in Nature? Do intermediate-mass black hole mergers occur in nature, and can such black holes serve as the long sought seeds of supermassive black holes? Is there a single thread which connects the formation of stellar-mass and supermassive black holes?

ET sites / 10

Update from the site-evaluation parameters group

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Site characterization and environmental-noise modeling are important tasks in the preparation of the ET site-selection procedure. The site-evaluation parameters (SEP) group was created to (1) facilitate the exchange of data, software, and information between the site teams, (2) give guidance for high-quality sensor installations, (3) achieve uniformity between the analysis methods so that results obtained at the two sites are easier to compare, (4) increase awareness in the ET collaboration of the importance of site-evaluation parameters, and (5) provide a software package that allows the modeling of environmental noise in ET based on the known properties of a site. In this talk, we present the status quo of these efforts.

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Seismic characterization of Sos Enattos and other ET candidate sites

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We will present the seismic studies done at the Sos Enattos mine and also in two other sites: the Matra mine and the Canfranc underground laboratory. In each location we have deployed a set of 3d time synchronized seismometers for an extended period of time. We will describe the experimental setup in each location and present the preliminary analysis of the data as well as the microquake frequency and its variation depending on sensor location. Finally we discuss the next steps for these experiments.

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Underground site characterization for Einstein Telescope

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The underground environment as well as all surrounding areas the facility which will host Einstein Telescope will have to be characterized for site selection, and after its building for monitoring all possible source of environmental noises. An overview of all physical-chemical processes affecting GW detectors in an underground environment is considered, particularly by: a) seismic microzonation - ground shaking, liquefaction susceptibility, landslide -; b) atmospheric boundary layer - surface radiative forcing, flow velocity, temperature, moisture, turbulence and vertical mixing -; c) infrasonic spectroscopy - severe weather, lee waves, lightning and upper-atmospheric lightning -; d) thermoeleastic damping - rock thermal conductivity, rock mechanics, acoustic/seismic stress/strain coupling; e) poromechanics of fluid-saturated porous media - rock permeability, percolation processes and water table changes, rock pore size variations and water-rock interaction -; f) electric potential difference in the ground - rock resistivity, streaming current, electrokinetic phenomena, induced magnetic field -; g) radioactivity – environmental and building materials -; *et al.*

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Seismological characterisation of the ET candidate site in Italy: the Sos Enattos mine (Sardinia).

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The background seismic vibrations of either natural or anthropogenic origin are generally dominated by surface Rayleigh waves, whose amplitude rapidly decrease with depth. As a consequence, underground sites offer the most favourable conditions for a low-noise environment. In this study, we provide an assessment of the ground vibrations at the dismissed Sos Enattos mines (Sardinia, Italy), one of the candidate sites for the construction of the ET gravitational wave detector. Earthquake rate at the site is extremely low, as evidenced from inspection of both historical and instrumental catalogues. Spectral amplitude and temporal evolution of the background seismic noise are assessed using continuous recordings collected at different sites above and within the mine. Most of the noise energy is concentrated within the 0.1-1 Hz frequency band, and it is markedly correlated with wave climate in the Tyrrhenian sea. Horizontal-to-Vertical spectral ratios indicate the lack of significant site amplification effects related to shallow impedance contrasts. We finally use recordings from

an underground mine blast to evaluate (1) the average P-wave velocity at the site, (2) an empirical attenuation relationship describing the distance decay of the peak ground velocity, and (3) a preliminary estimate of the shallow (~40m) shear-wave velocity profile from inversion of the Rayleigh-wave dispersion function.

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A feasibility study to design the underground facility hosting the Archimedes experiment: engineering challenges and key solutions

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The construction of the underground facilities to host Archimedes experiment poses some challenges for meeting the requirements on the suitable materials to reinforce the rock cavity and build the experimental room. Further constraints are linked to the operational conditions for accessing the site and allowing a safe installation and relocation of the experimental apparatus. Efficient drainage and ventilation systems for controlling dripping and air conditions should be designed. The work illustrates the results of laser scanning surveying conducted to define the optimal geometry of the hosting rock cavity and to evaluate the accessibility through the existing tunnels. Rock characterization, testing and monitoring, performed to define the excavation and reinforcement approachs, are also presented.

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The geometric configuration of the ET Sardinia: understanding the surface site characteristics and investigating the underground settings

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A preliminary study to identify the potential location of the ET Sardinia and the geometry of the underground tunnels based on available geological data and in-situ surveys was conducted. Different geometry configurations (Triangle and L-Topology) have been analysed using digital terrain models and deformation data from satellite data in order to investigate the present conditions at the surface facilities. By taking into account the accessibility and safety conditions of the surface infrastructures (descenderies to the underground labs) and the optimization of the excavation works in light of the geological setting, this study foreseen a deeper investigations to assess the final configuration. Further analysis and advanced surveying activity to be conducted in the future steps for the ET Sardinia design are also deliniated.

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EUregio Meuse-Rhin site update

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The 2011 ET Conceptual Design Report identified the EUregion Meuse-Rhin –the Belgium-Dutch-German border region– as a potential site for Einstein Telescope. This presentation will give an update of the drilling activity to assess the seismic noise and the plans towards a broader geological study. Other issues like a recently published socio-economic impact study, new gravitational-waves research groups, a general laser-interferometry R&D laboratory and the public/political climate will be addressed as well.

ET technology / 25

Technologies for 3G detectors

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This presentation will give an overview of technologies needed for 3G detectors, indicate levels of readiness and possible roadmaps.

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Maastricht 3G Prototype

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This talk will give an overview of the short- and long-term plans for the Maastricht 3G prototype interferometer (aka ETpathfinder). The key aims are to test the interplay of 'new' material (silicon), 'new' temperatures (120K and 10K) and 'new' wavelengths (1550nm and 2um) on systems level in a GW detector like environment and at low phase noise.

ET technology / 6

Cancellation of gravity noise in underground detectors

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Terrestrial gravity noise, also known as Newtonian noise (NN), will be a significant low-frequency noise contribution in present and future-wave detectors. Lowering this kind of noise is important since it will allow us to explore the existence of intermediate black holes and improve estimation of source parameters.

Current research focuses on NN from seismic fields. So far, only the cancellation of NN from seismic surface waves (Rayleigh waves) has been studied. However, also seismic body waves can give rise to Newtonian noise in surface detectors, but also (and especially) in underground detectors, where the test mass will be surrounded by rock. Building detectors underground, as planned for the Einstein Telescope, has the purpose to mitigate NN, but this will not be enough for ambitious low-frequency sensitivity targets as set by the Einstein Telescope. Additional mitigation can be achieved with coherent noise cancellation.

In this talk, results will be presented concerning the optimization of seismometer arrays for cancellation of NN from seismic body waves with Wiener filters. Optimal array configurations are shown together with the corresponding cancellation performance. The results make us confident that NN cancellation is a possible technology to help achieving the sensitivity target of the Einstein Telescope.

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Ice growth on cryogenic mirrors - thermal noise effects

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Recent work has shown that cryopumping effects between the room-temperature and cryogenic vacuum ducts in a cryogenic gravitational-wave detector can result in the growth of a layer of ice on a cryogenic test mass. Work by Kagra colleagues has examined the effect of this ice layer on quantum noise. Here, we consider the thermal noise implications of a growing ice layer. We show that the coating thermal noise could increase signficantly over one year of cryogenic operation - by

up to a factor of 10 if the ice grows at the rate observed in Kagra. We consider methods for reducing the impact of an ice layer, including annealing to reduce the mechanical loss of the ice and reducing the growth rate by acheiving lower vacuum pressure.

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Discussion on ET technology and R&D

Top-Down discussion / 20

ET: An assessment of the economic impact

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We develop a systematic analysis of the sources of economic impact associated with construction and operating phases of the ET research infrastructure. Specifically, based on a I-O technique we evaluate the direct and induced impact of ET in terms of total output, value added and employment effects. We also briefly discuss and analyse other types of impact including so called social effects.

Top-Down discussion / 40

Discussion

Discussion on the ET collaboratio, ESFRI roadmap and ET sites

Session 6 / 5

Dark energy with the Einstein Telescope

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Third-generation GW detectors will detect standard sirens up to cosmological distances. This will allow us to explore the dark-energy sector of generic modifications of General Relativity. In the dark energy sector a well-know observable is the equation of state of dark energy. However, its determination with ET (and with LISA) is not expected to be significantly better than what can already be obtained with electromagnetic observations (CMB, BAO, SNe). We will discuss recent work that shows that there is another way of testing the dark-energy sector, through modified GW propagation. This observable is more promising than the dark-energy equation of state, is specific to GW observations, and will allow both ET and LISA to reach a very competitive sensitivity to dark energy.

Session 6 / 11

Characterization of SGWB: synergy between LISA and ET

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Gravitational Waves (GWs) represent a unique tool to explore the physics and the microphysics of the universe. After the GW direct detections by the LIGO/Virgo collaboration the next target of modern cosmology is the detection of primordial GWs. Even if the main probe of primordial GWs has been so far considered the Cosmic Microwave Background, we will see in this talk how we can extract information about primordial GWs at smaller scale. The space based LISA interferometer, in addiction to detection and characterization of GWs of astrophysical origin, will give compelling information about the cosmological background of GWs. In this talk I will summarise part of the activity developed within the LISA Cosmology working group, and, in particular, I will discuss both on the ability of LISA to probe peculiar features of the Stochastic Gravitational Wave Background (SGWB) like non-Gaussianity and chirality and on the possibility of a model independent reconstruction of SGWB signals of different origins. These are tools which could be directly applied to Einstein Telescope to extract information about the SGWB.

Session 6 / 4

The THESEUS mission concept and its synergy with ET

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The Transient High-Energy Sky and Early Universe Surveyor (THESEUS) is a space mission concept currently under Phase A study by ESA as candidate M5 mission, aiming at exploiting Gamma-Ray Bursts for investigating the early Universe and at providing a substantial advancement of multi-messenger and time-domain astrophysics. Through an unprecedented combination of X-/gamma-rays monitors, an on-board IR telescope and automated fast slewing capabilities, THESEUS will be a wonderful machine for the detection, characterization and redshift measurement of any kind of GRBs and many classes of X-ray transients. In addition to the full exploitaiton of high-redshift GRBs for cosmology (pop-III stars, cosmic re-ionization, SFR and metallicity evolution up to the "cosmic dawn"), THESEUS will allow the identification and study of the electromagnetic counterparts to sources of gravitational waves which will be routinely detected in the late '20s / early '30s by next generation facilities like aLIGO/aVirgo, LISA, KAGRA, and Einstein Telescope (ET), as well as most classes of transient sources, thus providing an ideal sinergy with the large e.m. facilities of the near future like LSST, ELT, TMT, SKA, CTA, ATHENA. In particular, THESEUS will detect, localize and measure the redshift on tens/year e.m. counterparts (short GRBs, soft X-ray emission, kilonova emission) to GW signals coming from NS-NS and NS-BH mergers, and possibly other GW sources, detected by ET, thus providing unique clues to the physics and progenitors of these phenomena and allow their full exploitation for fundamental physics and cosmology.

ET technology / 8

A proof of principle experiment for frequency-dependent squeezing generation with EPR entanglement: status and plans

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Squeezed light injection, as a method for the reduction of quantum noise, has been already demonstrated in the interferometric GW detectors GEO and LIGO . Recently also Advanced Virgo implemented this solution, and it will join the next observation run (O3), with frequency independent squeezed vacuum injected. This will allow a reduction of the shot noise, which is due to the quantum phase fluctuations of the coherent vacuum at the interferometer output port, with a corresponding improvement of the detector sensitivity in the high-frequency region of the detection band.
Quantum noise is also present, as Radiation Pressure noise (RPN), at low frequencies due to the amplitude vacuum fluctuations affecting the position of the suspended test masses. RPN does not limit the current sensitivity of interferometric GW detectors, as it is covered by technical noises.
However in the next future, when low-frequency technical noises will be reduced, RPN will be relevant for the detector sensitivity.
One of the proposed techniques, to have a broad band quantum noise reduction, is the use of a long external filter cavity, that will allow a frequency dependent rotation of the squeezing angle, starting from the frequency independent squeezed vacuum produced by a degenerate Optical Parametric Oscillator (OPO).
In this talk I will present an alternative method that makes use of quantum correlations of two EPR-entangled beams produced by a non-degenerate OPO, and of their different propagation inside the interferometer. The advantage is that the rotation of the squeezing angle, and then a frequency dependent squeezing, can be obtained with a compact apparatus and without the costs required by the infrastructure for the filter cavity.
A first step towards the implementation in the next generation detectors is to demonstrate the squeezing angle rotation on a table-top experiment with the injection of the two EPR entagled beams in a test cavity.
The proof-of-principle experiment will be based on an optical setup that was developed at EGO to demonstrate frequency independent squeezing in the audio-frequency band. This will be properly modified to have a non-degenerate OPO and a dual homodyne detection system to measure conditional squeezing.

ET technology / 21

Molecular Dynamics simulations to study dissipation in amorphous materials: starting with Ta_2O_5

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In interferometric gravitational wave detectors, thermal noise from the mirrors represents currently the major limitation in most of the detection band. It originates from mechanical dissipation, which is rather low in the substrates, but orders of magnitude higher in the coating films. Although a significant experimental effort has led to some improvements during these years, there is still a lack of fundamental understanding of the involved dissipation mechanisms, which is critically limiting the development of effective design tools for successful coating architectures. The common approach to this problem builds on the framework of the so-called two-level systems (TLS) model [1]: dissipation is due to the atomic motion originating from a transition between two potential energy minima, promoted by the coupling between thermal activation and mechanical waves. In the last decades, the TLS model has been used to fix experimental data or to predict dissipation via atomic scale simulations, paying the price of simplifying approximations and heavy computations. In this work we propose a different numerical approach to study dissipation in glasses, which, in contrast to TLS, is theory-independent as it does not require any a priori assumption [2]. We apply the experimental protocol of the mechanical spectroscopy to atomistic simulations, in which a glass is subjected to oscillatory deformation at a given frequency f and the storage and loss moduli are measured. We test the method on glassy Ta_2O_5, created by melt cooling. We find that in the GHz range the quality factor follows a robust power-law dependence on f, whose specific form depends on temperature and thermal history. Further, after an extrapolating to the kHz range of interest, simulation results exhibit strong qualitative and satisfying quantitative agreement with the existing experimental data. Our results suggest that in silico mechanical spectroscopy has the potential to push the predictive power down to millisecond timescale in amorphous coatings.

References:
[1] W.A. Phillips, J. Low. Temp. Phys. 7, 351 (1972).
[2] F. Puosi, F. Fidecaro, S. Capaccioli, D. Pisignano and D. Leporini, in preparation.

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ET Coating R&D @ UniSA/UniSannio

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The University of Sannio and the University of Salerno joined forces to develop advanced optical coatings for 3G gravitational wave detectors.
We own a fully programmable plasma-assisted e-beam optical-coating deposition system with sub-nm accuracy/repeatability, using up to 6 different materials in a single batch, and state-of-the-art thin-film characterization facilities including AFM, STM, XRD, SEM and TEM.
Identifying cryo-compatible high and low index optical materials (free from the well known blow-up of mechanical losses at cryo-temperatures observed in the materials used in 2G detectors) is a key problem for ET.
Recent results, obtained in collaboration with NTHU, demonstrated that nanolayered composites made by a glassy but not cryo-friendly material like Silica, and a cryo-friendly material but prone to crystallization upon annealing like Titania tolerate very high post-deposition annealing temperatures without crystallizing, and do not exhibit a cryogenic mechanical-loss peak.
In the light of these results, nanolayered Silica/Alumina composites are suggested as an excellent candidate low-index (n~1.6) cryo-friendly coating material for ET, possibly better than currently candidate Silica-doped Hafnia (n~1.8) .
The expected performance of a whole 5ppm transmittance coating based on a-Si and nanolayered SiO2::Al2O3 will be illustrated together with our deposition and testing plans for the next months.

Poster Session / 12

A 6D INTERFEROMETRIC INERTIAL ISOLATION SYSTEM

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Ground-based detectors are strongly limited at low frequencies [5 - 30 Hz]. Unlocking these frequencies requires the development of new technologies, and will allow terrestrial detection of new, and

more distant sources. Additionally, source localisation and forewarning will provide opportunities for spectacular multi-messenger observations.
We propose a new kind of inertial isolation system that can overcome these limitations by a combinations of materials, interferometry and design.

Poster Session / 15

Constraining parameters of coalescing binary systems with Einstein Telescope alone

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Abstract
Einstein Telescope is a proposed third-generation gravitational wave detector which is expected to have an increased broadband sensitivity by a factor of 10 with respect to advanced detectors while also extending the low frequency sensitivity of ground based gravitational wave interferometers below 10 Hz. Gravitational wave observations using a network of detectors permits a direct and independent measurement of the distance to the source systems. Knowing the redshift of the source, the inspiraling binary systems can be used as standard sirens to extract cosmological information. Since, the redshift and the system chirp mass are degenerate in gravitational wave observations with a single detector, it is usually assumed that the source redshift is obtained from the electromagnetic counterparts. The current design of the Einstein Telescope consists of three overlapping interferometers, arranged in an equilateral configuration with arm-opening angles of 60 degrees. In this work we consider a joint analysis of coalescing binaries detection with three ET-D interferometers in the triangular configuration to constrain their luminosity distances and chirp masses. We present the method and investigate its accuracy.

Poster Session / 23

Impact of the ET research infrastructure

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We present the estimates of the impacts related to the construction and operating phases of the Einstein Telescope (ET) research facility. Precisely, we provide estimates of the total output, value added and employment impacts of ET as well as some preliminary estimates of social impact.

Poster Session / 14

Adaptive denoising of acoustic noise injections

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A tool for time series analysis based on adaptive methodologies such as Empirical Mode Decomposition (EMD) and its time varying version tvf-EMD, has been developed and applied to characterise seismometer data monitoring Virgo North End Building (NEB) recording during four different acoustic noise injections. The tool quantifies the trend/baseline wandering eventually present in the data and adaptively extract it removing the residual term of standard EMD. Furthermore, it extracts narrowband oscillatory modes which are possibly both nonlinear and/or nonstationary, using the tvf-EMD algorithm. Subsequently, the persistency of extracted modes is evaluated by means of Detrended Fluctuation Analysis (DFA), providing the Hurst exponent of each mode. Denoising can be then achieved by thresholding on the mode's Hurst exponent. Then, due to the completeness property, extracted modes quantitatively describe distinct bands of the Fourier spectra. The Hilbert-Huang transform can be obtained performing Hilbert Spectral Analysis on the obtained modes, providing a high resolution time frequency representation of the analysed data, capable of tracking nonlinearities and nonstationarities.
The induced seismic perturbation can be separated from the underlying nonlinear nonstationary seismic noise. Adaptive methodologies such as tvf-EMD should be employed for site characterization studies of underground detectors such as the Einstein Telescope.

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Seismic noise measures for underground gw detection. Experience from the Matra site

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The selection of sites for underground gravitational wave detectors based on spectral and cumulative characterization of the low frequency seismic noise. The evaluation of the collected long term seismological data in the Mátra Gravitational and Geophysical Laboratory revealed several drawbacks of the previously established characteristics. Here we demonstrate the problematic aspects of the recent measures and suggest more robust and more reliable methodology. Our recommendations are the use of median of the data instead of the mode in the spectral characterization and the modification of the frequency limits of the cumulative noise measures.

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Geological support for Sardinia ET project

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Sardinia ET project involves the realization of an underground infrastructure with two possible geometrical arrays which develop along approximately 30 km of tunnel. The site is near Sos Enattos mine (North-eastern Sardinia), where currently physics laboratories are already active.
The positioning and orientation of the infrastructure and the relative tunnel tracks were chosen taking into account the geological, hydrographic and geomorphological features of the area after a geological surveys.
In detail, the occurrence of the Mesozoic calcareous massif of Monte Albo, which is involved in

thick-skinned tectonic, led to exclude the eastern side of the area. In fact, the large mass of carbonate rocks rooted within the basement, could host intense karstic circulation. The north-western area instead, is characterized only by the Palaeozoic metamorphic basement (micaschist, quarzites and orhogneiss) intruded by Variscan granites. Here, the two different designs were placed taking into account the toughness needed by rocks hosting large underground voids such as those planned at the vertices. For this reason the tracks were chosen so that vertices felt on orthogneiss and granites.
To complete the knowledge of the geotechnical properties of the rocks, a thorough physical-mechanical characterization was carried out on the lithotypes crossed by the infrastructures. Among the different parameters, dry density, water absorption, capillary water absorption, open porosity, ultrasonic speed and uniaxial compressive strength were assessed. All tests followed the UNI-EN standard procedures.
Finally, some environmental issue were addressed: the first concerning the utilize of the excavation wastes and the second the natural radioactivity by mean of a radiological survey using a portable spectrometer in order to evaluate the 40K, 238U, 232Th activity in these rocks.

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g-MAG: Materials for Gravitational Astronomy

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There are no other large instruments that are limited so much by availability of materials like the Earth based GW detectors. Thermal noise and optical absorption in mirrors and their suspensions are a strong limiting factor for future upgrades of existig detectors and also in new projects like Einstein Telescope. A new group at the Insitut Lumière Matière, Lyon, has been formed with the aim to study the origin of thermal noise in amorphous materials and to develop the technology of sapphire for large missor substrates and monolithic suspensions.

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CORRECTION OF OPTICAL ABERRATION: LESSONS FROM 2nd GENERATION TOWARDS FUTURE DETECTORS

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Wave-front aberrations in the core optics of interferometric gravitational waves detectors can represent a strong limitation to their operation and sensitivity. These aberrations are due to intrinsic defects in the optics (surface figure errors and refraction index inhomogeneity) and to the rise of thermal effects, i.e. optical power absorption in the substrate and coatings of the test masses that induces both an increase of the optical path length (thermal lensing) and a thermo-elastic deformation of the optic itself along the optical axis. All these imperfections can be compensated for by generating proper optical path length corrections. An adaptive optical system has been installed and is operating in Advanced Virgo. The high frequency component of Einstein Telescope will also suffer from optical aberrations as in second generation interferometers, with the additional issue of the possible use of the LG33 mode, instead of the TEM00. Here, the ongoing research activity for improvements of the adaptive optical system in view of third generation detectors is presented

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The Archimedes Experiment and the SAR-GRAV laboratory

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The Archimedes experiment is devoted to the measurement of the interaction of vacuum fluctuations and gravity throught the use of a criogenic balance to be placed in the undergriound site of Sos-Enattos, in the SAR-GRAV laboratory. The measurement consists in weighing the condensation energy of stratified type II superconductors, like YBCO, around the transition temperature. The need of a seismically quite site motivates its construction in SAR-GRAV. In the poster the status of the experiment will be illustrated, togheteher with the required specifications on seismic noise and the final expected sensitivity.