Einstein Telescope

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LIGO/Virgo/KAGRA O3 Run

- 11 months of data taking
- 56 public alerts
- 39 candidates published in the O3a catalogue
GW190814 – Loud event

- Detected online by Livingstone and Virgo, Hanford in commissioning mode, but undisturbed
  - Hanford data recovered offline
  - Best localised source (green skymap 23 deg$^2$)
  - The most mass asymmetric GW event detected

\[ q = \frac{m_2}{m_1} \]
GW190814 – Higher order multipoles

• Being the mass distribution so asymmetric:

GW190814 has the strongest evidence for Higher order multipoles that we have ever detected.

SNR in 33 multipole nearly as high as the total SNR of GW151012

• Test of GR on strongly asymmetric mass distribution (GR “validated”)
GW190521 \( M_1 = 85^{+21}_{-14} M_\odot, M_2 = 66^{+17}_{-18} M_\odot \) at \( z \sim 0.82 \) (5.3Gpc)
Remnant \( M_f = 142^{+28}_{-16} M_\odot \)

- Very special event:
  - \( M_1 \), the black hole that should not exist
  - \( M_f \), the first IMBH ever seen

GW190521: LIGO-Virgo sensitivity to the BBH merger

- Higher masses correspond to lower frequency GW emission
BH masses

LIGO & Virgo will have marginal access to IMBH because of the “seismic wall” limiting the sensitivity at low frequency.

Stellar mass BHs

Intermediate Mass Black Holes (IMBHs)

Supermassive black holes

10 M_☉, 20 M_☉, 100 M_☉, 10^3 M_☉, 10^5 M_☉

GW190521 primary mass ~85M_☉

GW190521 merger remnant ~142M_☉
OK, all done?

- aLIGO and AdV achieved awesome results with a reduced sensitivity.
- When they will reach or over-perform their nominal sensitivity can we exploit all the potential of GW observations?

- 2nd generation GW detectors will explore local Universe, initiating the precision GW astronomy, but to have cosmological investigations a factor of 10 improvement in terms detection distance is needed.
Detection distance of GWD

3G/LISA Target

Image credit: NAOJ/ALMA http://alma.mtk.nao.ac.jp/
The Einstein Telescope

And Cosmic Explorer (CE) in US
Wideband or Narrow band?

• The design of the ET observatory is driven by the physics objectives
  • At what frequency are they?

Everywhere!

We need a wide band observatory
(with special attention to low frequency)
ET science targets

• A recent science case study for ET is here:
  • M.Maggiore et al, JCAP, 2020, 03, pp.050. ⟨10.1088/1475-7516/2020/03/050⟩
  • Hereafter a short list

• Astrophysics
  • Black Hole physics
  • Neutron star physics
  • Multi-messenger astronomy
  • Core Collaps Sne
  • Isolated NS

• Fundamental physics
  • Testing GR
    • Perturbative regime
      • Inspiral phase of BH, post Newtonian expansion
    • Strong field regime
      • Physics near BH horizon
      • Exotic objects
  • QCD
    • NS interior structure
  • Dark matter
    • Primordial black holes
    • Axions
  • Dark Energy
    • DE equation of state
    • Modified propagation of GW

• The “Unexpected”
  • ???
ET Key ingredients

Factor 10 better sensitivity in a wide range of frequency with a specific attention to low frequency (<10Hz)

• Einstein Telescope is a 3rd generation Gravitational Wave Observatory
  • It is, first of all, a new Research Infrastructure

• Capable to host ET and its upgrades
• Capable to host 4G, 6G, ...

Observation (rather than detection) is the core business:

Requirements
• Wide frequency range
• Massive black holes (LF focus)
• Localisation capability
• (more) Uniform sky coverage
• Polarisation disentanglement
• High Reliability (high duty cycle)
• High SNR

Design Specifications
• Xylophone (multi-interferometer) Design
• Underground
• Cryogenic
• Triangular shape
• Multi-detector design
• Longer arms
Key performances expected in ET

- BBH up to $z \approx 50$
  - $10^6$ BBH/year
  - Masses $M_T \gtrsim 10^3 M_\odot$
- BNS to $z \approx 2$
  - $10^5$ BNS/year
  - Possibly $O(10-100)$/year with e.m. counterpart
- High SNR
Proposal submitted by:
- **Italy** (Lead Country)
- Netherlands
- Belgium
- Spain
- Poland

- ET CA signed by 41 institutions
- INFN and Nikhef are the coordinators of the consortium
30/06/2021: ET enters in the ESFRI roadmap

ET Einstein Telescope ed EuPRAxia: due grandi infrastrutture di ricerca competitive a livello mondiale, rispettivamente nella ricerca sulle onde gravitazionali e nello sviluppo di futuri acceleratori di particelle al plasma. Sono questi i due progetti internazionali di cui l’INFN Istituto Nazionale di Fisica Nucleare è capofila, e che l’Italia attraverso il MUR Ministero dell’Università e della Ricerca ha candidato lo scorso settembre per la Roadmap 2021 di ESFRI European Strategy Forum on Research Infrastructure, il forum strategico europeo che individua le grandi infrastrutture di ricerca su cui investire a livello europeo. Dopo un lungo e accurato processo di valutazione dei progetti candidati, il 30 giugno, l’Assemblea di ESFRI ha approvato entrambi, ET ed EuPRAxia, che entrano così nel novero delle grandi infrastrutture di ricerca su cui l’Europa punterà nel prossimo futuro.

"L’inclusione di ET ed EuPRAxia nella Roadmap di ESFRI è un importante risultato che ne rafforza il valore strategico a livello europeo", commenta Antonio Zoccoli, presidente dell’INFN. "Le grandi infrastrutture di ricerca sono una risorsa per la scienza e la conoscenza, ma anche per lo sviluppo industriale, l’innovazione tecnologica, la crescita economica, culturale e sociale. Forti della leadership scientifica del nostro Paese a livello internazionale, metteremo il massimo impegno per il loro sviluppo, e per valorizzare la candidatura del sito italiano a ospitare ET, e siamo certi che con il sostegno del MUR, della Regione Sardegna, delle istituzioni nazionali e locali, abbiamo ottime possibilità di raggiungere l’obiettivo, a beneficio del territorio e del Paese".

On June 30th, the European Strategy Forum on Research Infrastructures (ESFRI) decided to include the Einstein Telescope in the 2021 upgrade of its roadmap. This confirms the relevance of this major international project for a next generation gravitational waves observatory for the future of research infrastructures in Europe and gravitational wave research at a global level.
30/06/2021: ET enters in the ESFRI roadmap

• Why it is so important for ET to be in the ESFRI roadmap?
  • ESFRI has not funds
  • But to be in the ESFRI roadmap
    • Is a quality stamp that certifies the readiness level of the project: it states the passage from the design phase to the preparatory phase
    • Allows to access a (small) financial support from the European Commission for the preparatory phase
    • Allows to access specific (and potentially large) national and regional funds in Europe
    • Facilitates the coordination of different European countries at government level targeting the realisation of the infrastructure
ET organisation
ET collaboration current organisation

ET Steering Committee

Specific Boards

- SPB: Site Preparation Board
  - Site Studies
  - Environmental studies
  - Geophysical studies
  - Data management std.
  - Analysis tools and data comparison
  - Detector Optimisation
  - Community relations
  - Costs and socio-economic impact
  - Legal

- OSB: Observation Science Board
  - Fundamental Physics
  - Cosmology
  - Population Studies
  - Multimessenger Obs.
  - Synergies with GWDs
  - Nuclear Physics
  - Transient GW Sources
  - Waveforms
  - Scientific potentials ...
  - Data Analysis Platform

- ISB: Instrument Science Board
  - Suspensions
  - Optics
  - Interferometer
  - Vacuum and Cryogenics
  - Active Noise Mitigation
  - Civil Infrastructures

- EIB: E-Infrastructure Board
  - On-site Infrastructure
  - Distributed infrastructure
  - Software & frameworks

Divisions
Q1: Enabling Technologies

The multi-interferometer approach asks for two parallel technology developments:

**ET-LF:**
- Underground
- Cryogenics
- Silicon (Sapphire) test masses
- Large test masses
- New coatings
- New laser wavelength
- Seismic suspensions
- Frequency dependent squeezing

**ET-HF:**
- High power laser
- Large test masses
- New coatings
- Thermal compensation
- Frequency dependent squeezing

New technology in cryo-cooling
New technology in optics
New laser technology
High precision mechanics and low noise controls
High quality opto-electronics and new controls

Einstein Telescope
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*Marica Branchesi - Michele Maggiore - Ed Porter*

**ET** Einstein Telescope

**Kick-off workshop end of September 2021**
How to join?
If you are interested in contributing, please get in touch with one of the division or working group chairs

Check out the ISB webpage: https://wiki.et-gw.eu/ISB/WelcomePage

The Instrument Science Board (ISB) is described in more detail in:
https://apps.et-gw.eu/tds/ql/?c=15709
https://apps.et-gw.eu/tds/ql/?c=15707
Letter of Intent

on the scientific collaboration between
the Einstein Telescope collaboration
and
the KAGRA collaboration

This letter outlines the intent of the two parties, the Einstein Telescope collaboration (ET collaboration, hereafter) and the KAGRA collaboration, to collaborate in the development of the technologies needed to upgrade the current detectors and to realise the 3rd generation of gravitational wave (GW) observatories such as ET.
Evolution of the ET collaboration

• After the ESFRI announce, the process to realise the ET collaboration is speeding up.

• The ET steering committee will evolve toward a more complex structure having an operative bodies (executive board, ...) and representative bodies (Collaboration board, ...)

• The relationship with the “project” component are going to be defined

• Target: Fall 2021
SPB: ET sites under characterisation

**Euregio Meuse-Rhine**
- A 250-m deep borehole has been excavated and equipped
  - Seismic data under acquisition and analysis
- 3-5 other boreholes expected
- Extensive active and passive site characterisation with sensor arrays in 2021
- Good seismic noise attenuation given by the particular geological structure
- ET pathfinder centre under construction
- 15+15M€ funding through Interreg grants
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**Sardinia**
- Long standing characterisation of the mine in one of the corners continuing
  - Seismic, magnetic and acoustic noise characterisation ongoing at different depth in the mine
- Underground laboratory under construction (SarGrav)
- A 290m borehole has been excavated and it will be equipped
- A second borehole to be excavated in the summer 2021
- Intense & international surface investigations programme in Summer 2021
- 17+3.5+1+11M€ funding through national and regional funds
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Einstein Telescope

First results at Sos Enattos

SOE0
Surface

SOE1
-84m

SOE2
-111m

L. Naticchioni — GWADW21 — May 17th — 21st 2021

DAQ self-noise limit

2021 data
January-April

- L. Naticchioni et al., Characterization of the Sos Enattos site for the Einstein Telescope, IPCS1468, 2020
- M. DiGiovanni et al., A seismological study of the Sos Enattos Area—the Sardinia Candidate Site for the Einstein Telescope, SRL, 2020 https://doi.org/10.1785/0220200186
- A. Allocca et al., Seismic glitchness at Sos Enattos site: impact on intermediate black hole binaries detection efficiency, EPJP, 2021 https://doi.org/10.1140/epjp/s13360-021-01450-8
ET Structure - 2020

- Until now: A broad ET scientific community;
Governance proposal for the Preparation phase

An interim structure for the ET project organization until establishment of a Council

**Consortium**
Stan Bentvelsen
Antonio Zoccoli

**Project directorate**
Jo v.d. Brand
Fernando Ferroni

**ET Collaboration**
Michele Punturo
Harald Lück
Proposal for governance in the construction phase

Structure during Implementation phase

Council
Assisted by several bodies (e.g. STAC)

Project Directorate
evolves into Einstein Telescope Observatory

ET Observatory will be a legal entity
and will have significant staff

Verify by expert panel on governance and project organization