Status of the Newtonian Noise work package

Soumen Koley, Maria Concetta Tringali

4th Site Characterization Board Workshop

Sapienza University of Rome, Physics Department

April 14th, 2026

ET-0203A-26

NN work package

Active Noise Mitigation division (co-chairs: Luca Naticchioni and Conor Mow-Lowry)

The division is divided into 5 work packages with 2 co-chairs each:

- **Newtonian Noise** (Soumen Koley and Maria Tringali)
- **Environmental Sensors** (Rosario De Rosa and Mariusz Suchenek)
- **Magnetic Noise** (Irene Fiori and Barbara Garaventa)
- **Inter-platform motion** (Tomislav Andric and Sina Koehlenbeck)
- **LF control noise** (Artem Basalaev and Michele Valentini)

Objectives of NN work package

The work package focuses on modeling and mitigating Newtonian Noise, with a strong emphasis on cancellation strategies.

- *Site characterization:* reconnaissance studies are performed using dense sensor arrays to identify dominant environmental sources, quantify field composition (e.g., surface vs body waves), and determine the elastic properties of the surrounding medium

- *NN modelling:* the environmental observables are used to construct and validate numerical or analytical models of the Newtonian noise.

- *Sensor-array optimization:* once a representative model of the ambient field is available, optimization algorithms are used to design sensor layouts that maximize NN subtraction performance while accounting for site geometry and practical constraints

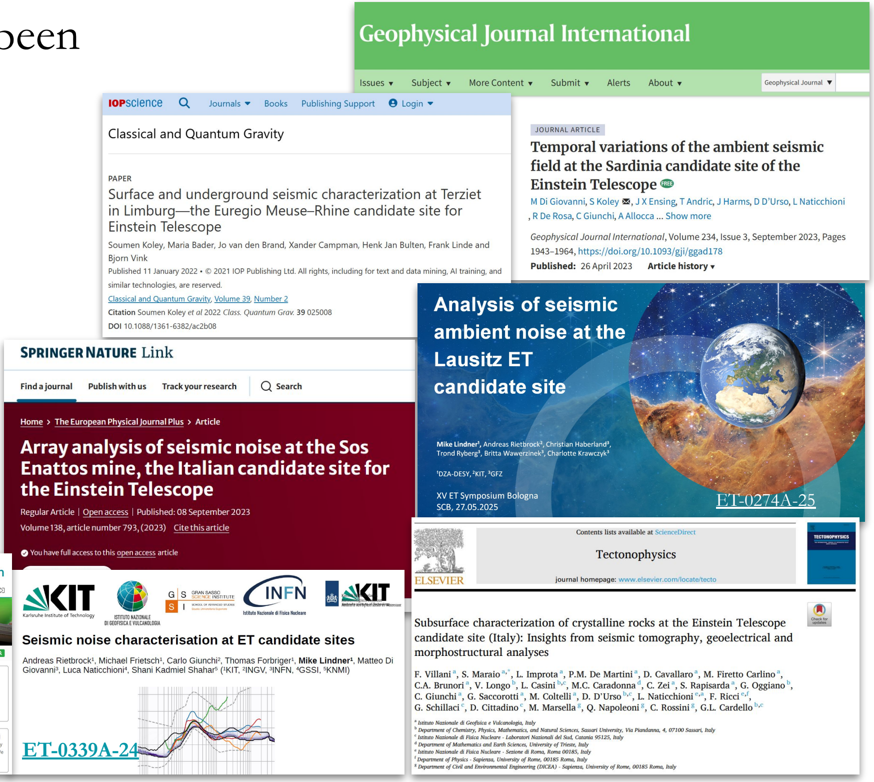
- *Noise cancellation:* it involves implementing algorithms - either online or offline - that use the sensor array outputs to estimate and subtract the NN contribution from the detector strain channel. Proven approaches include stationary and adaptive Wiener filtering although recent studies have demonstrated promising results using advanced machine-learning algorithms.

What has already been done

Extensive site characterization campaigns have been carried out across candidate sites.

- Sardinia candidate site (link, INGV)
- Euregio Meuse–Rhine candidate site (link)
- Lausitz candidate site (ET-0274A-25)

These studies provide the experimental basis for NN modeling and mitigation.



What has already been done

A significant effort has already been devoted to both modelling and cancellation of Newtonian Noise, using analytical, numerical and also data-driven approaches.

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Classical and Quantum Gravity

PAPER

Newtonian-noise characterization at Terziet in Limburg—the Euregio Meuse–Rhine candidate site for Einstein Telescope

Maria Bader, Soumen Koley, Jo van den Brand, Xander Campman, Henk Jan Bulten, Frank Linde and Bjorn Vink

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Classical and Quantum Gravity, Volume 39, Number 2

Citation Maria Bader *et al* 2022 *Class. Quantum Grav.* **39** 025009

DOI 10.1088/1361-6382/ac1be4

Eur. Phys. J. Plus (2022) 137:687
https://doi.org/10.1140/epjp/s13360-022-02851-z

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

A lower limit for Newtonian-noise models of the Einstein Telescope

Jan Harms[1,2,a], Luca Naticchioni[3], Enrico Calloni[4,5], Rosario De Rosa[4,5], Fulvio Ricci[3,6], Domenico D'Urso[7,8]

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Classical and Quantum Gravity

PAPER • OPEN ACCESS

Joint optimization of seismometer arrays for the cancellation of Newtonian noise from seismic body waves in the Einstein Telescope

Francesca Badaracco, Jan Harms and Luca Rei

Published 4 January 2024 • © 2024 The Author(s). Published by IOP Publishing Ltd

Classical and Quantum Gravity, Volume 41, Number 2

Citation Francesca Badaracco *et al* 2024 *Class. Quantum Grav.* **41** 025013

DOI 10.1088/1361-6382/ad1715

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Classical and Quantum Gravity

PAPER

Optimization of seismometer arrays for the cancellation of Newtonian noise from seismic body waves

F Badaracco and J Harms

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Classical and Quantum Gravity, Volume 36, Number 14

Citation F Badaracco and J Harms 2019 *Class. Quantum Grav.* **36** 145006

DOI 10.1088/1361-6382/ab28c1

PAPER • OPEN ACCESS

A study of deep neural networks for Newtonian noise subtraction at Terziet in Limburg—the Euregio Meuse-Rhine candidate site for Einstein Telescope

Vincent van Beveren, Maria Bader, Jo van den Brand, Henk Jan Bulten, Xander Campman, Soumen Koley and Frank Linde

Published 18 September 2023 • © 2023 The Author(s). Published by IOP Publishing Ltd

Classical and Quantum Gravity, Volume 40, Number 20

Citation Vincent van Beveren *et al* 2023 *Class. Quantum Grav.* **40** 205008

DOI 10.1088/1361-6382/acf3c8

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Design and implementation of a seismic Newtonian noise cancellation system for the Virgo gravitational-wave detector

Regular Article | Open access | Published: 13 January 2024

Volume 139, article number 48, (2024) Cite this article

Adaptive algorithms for low-latency cancellation of seismic Newtonian-noise at the Virgo gravitational-wave detector

Soumen Koley* and Jan Harms

Atmospheric Newtonian noise modeling for third-generation gravitational wave detectors

D. Brundu[1,*], M. Cadoni[1,2,†], M. Oi[1,2,‡], P. Olla[1,3,§], and A. P. Sanna[1,2,‖]

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Phys. Rev. D **106**, 064040 – **Published 22 September, 2022**

DOI: https://doi.org/10.1103/PhysRevD.106.064040

Existing NN tools

- NN wp collected a list of *open access* tools to be considered for the development of site-dependent noise models and for the evaluation of mitigation techniques.

List of tools and reference person:

- **Newtonian Noise optimizations** - Francesca Badaracco ✓
- **NewtonForge-3D** - Tomislav Andric ✓
- **SeisNN** - Andreas Rietbrock ✓
- **pySeis1DNN** and **pySeis3DNN** - Soumen Koley ✓ ✓
- **Prediction of environmental vibration due to anthropogenic sources and computation of Newtonian Noise** - Geert Degrande ✓
- **FraNC** - Tim Kuhlbusch ✓
- **ParaArrayOpt** - Johannes Erdmann ✓

- The tools cover three main fields

NN modelling

- Seismic field and gravity perturbation modelling
- Analytical and numerical approaches (1D/3D, realistic geology)

Array optimization

- Design of sensor layouts for NN cancellation
- Optimization based on model assumptions or data-driven approaches

Cancellation

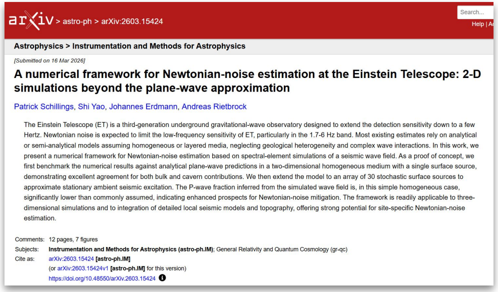
- Wiener filtering, adaptive methods, and machine learning techniques
- Performance evaluation and comparison frameworks

Status
ready
nearing completion
under development

Towards a coherent NN tool framework

- A variety of NN tools has been developed within the collaboration.
  - Tools are at different stages of development
- New developments and tools are continuously emerging across different groups.
- These efforts represent a valuable and active contribution from the community.
- A coordinated validation and usage of these tools is needed to support NN studies and site selection for ET.

Recent tools


arXiv > astro-ph > arXiv:2603.15424

Astrophysics > Instrumentation and Methods for Astrophysics

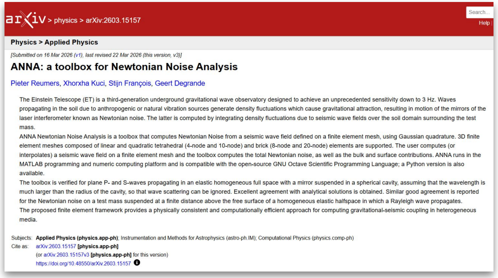
[Submitted on 16 Mar 2026]

A numerical framework for Newtonian-noise estimation at the Einstein Telescope: 2-D simulations beyond the plane-wave approximation

Patrick Schillings, Shi Yao, Johannes Erdmann, Andreas Rietbrock

The Einstein Telescope (ET) is a third-generation underground gravitational-wave observatory designed to extend the detection sensitivity down to a few Hertz. Newtonian noise is expected to limit the low-frequency sensitivity of ET, particularly in the 1.7-6 Hz band. Most existing estimates rely on analytical or semi-analytical models assuming homogeneous or layered media, neglecting geological heterogeneity and complex wave interactions. In this work, we present a numerical framework for Newtonian-noise estimation based on spectral-element simulations of a seismic wave field. As a proof of concept, we first benchmark the numerical results against analytical plane-wave predictions in a two-dimensional homogeneous medium with a single surface source, demonstrating excellent agreement for both bulk and cavern contributions. We then extend the model to an array of 30 stochastic surface sources to approximate stationary ambient seismic excitation. The P-wave fraction inferred from the simulated wave field is, in this simple homogeneous case, significantly lower than commonly assumed, indicating enhanced prospects for Newtonian-noise mitigation. The framework is readily applicable to three-dimensional simulations and to integration of detailed local seismic models and topography, offering strong potential for site-specific Newtonian-noise estimation.

Comments: 12 pages, 7 figures
Subjects: **Instrumentation and Methods for Astrophysics (astro-ph.IM)**; General Relativity and Quantum Cosmology (gr-qc)
Cite as: arXiv:2603.15424 **[astro-ph.IM]**
(or arXiv:2603.15424v1 **[astro-ph.IM]** for this version)
https://doi.org/10.48550/arXiv.2603.15424


arXiv > physics > arXiv:2603.15157

Physics > Applied Physics

[Submitted on 16 Mar 2026 (v1), last revised 22 Mar 2026 (this version, v3)]

ANNA: a toolbox for Newtonian Noise Analysis

Pieter Reumers, Xhorxha Kuci, Stijn François, Geert Degrande

The Einstein Telescope (ET) is a third-generation underground gravitational wave observatory designed to achieve an unprecedented sensitivity down to 3 Hz. Waves propagating in the soil due to anthropogenic or natural vibration sources generate density fluctuations which cause gravitational attraction, resulting in motion of the mirrors of the laser interferometer known as Newtonian noise. The latter is computed by integrating density fluctuations due to seismic wave fields over the soil domain surrounding the test mass.
ANNA Newtonian Noise Analysis is a toolbox that computes Newtonian Noise from a seismic wave field defined on a finite element mesh, using Gaussian quadrature. 3D finite element meshes composed of linear and quadratic tetrahedral (4-node and 10-node) and brick (8-node and 20-node) elements are supported. The user computes (or interpolates) a seismic wave field on a finite element mesh and the toolbox computes the total Newtonian noise, as well as the bulk and surface contributions. ANNA runs in the MATLAB programming and numeric computing platform and is compatible with the open-source GNU Octave Scientific Programming Language; a Python version is also available.
The toolbox is verified for plane P- and S-waves propagating in an elastic homogeneous full space with a mirror suspended in a spherical cavity, assuming that the wavelength is much larger than the radius of the cavity, so that wave scattering can be ignored. Excellent agreement with analytical solutions is obtained. Similar good agreement is reported for the Newtonian noise on a test mass suspended at a finite distance above the free surface of a homogeneous elastic halfspace in which a Rayleigh wave propagates.
The proposed finite element framework provides a physically consistent and computationally efficient approach for computing gravitational-seismic coupling in heterogeneous media.

Subjects: **Applied Physics (physics.app-ph)**; Instrumentation and Methods for Astrophysics (astro-ph.IM); Computational Physics (physics.comp-ph)
Cite as: arXiv:2603.15157 **[physics.app-ph]**
(or arXiv:2603.15157v3 **[physics.app-ph]** for this version)
https://doi.org/10.48550/arXiv.2603.15157

Thank you for your attention!