Journal of Physics:
Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: Hans Van Haevermaet and the Einstein Telescope Pathfinder (ET-PF) collaboration 2026 *J. Phys.: Conf. Ser.* **3177** 012095

GR24-AMALDI16 IOP Publishing
Journal of Physics: Conference Series **3177** (2026) 012095 doi:10.1088/1742-6596/3177/1/012095

Status of ETpathfinder

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Abstract. Third-generation gravitational wave observatories, such as the Einstein Telescope (ET) and Cosmic Explorer, aim for sensitivity improvements of at least a factor of ten over a wide frequency range compared to the current operational detectors. To finalise the design of these third generation detectors and to further develop and qualify their subsystems, dedicated test facilities are required. The ETpathfinder prototype consists of full interferometer configurations and aims to provide a high sensitivity test facility in a similar environment as ET. The key technologies that will be implemented are lasers and optics at 1550 nm and 2090 nm, silicon test masses, cryogenic cooling techniques, and advanced quantum-noise reduction schemes. In these proceedings we will present a general status update of the ETpathfinder experiment.

1 Introduction

The ETpathfinder experiment [1, 2] is a research and development infrastructure specifically designed to test new Einstein Telescope technologies in a low noise environment with a full interferometer setup. The four key technologies that ETpathfinder aims to test and further develop are: a) operation at cryogenic temperatures at 10-15 K and 123 K; b) silicon mirrors; c) novel laser wavelengths at 1550 nm and 2090 nm; and d) advanced quantum noise reduction techniques. This will be achieved by constructing two Fabry-Perot Michelson interferometers (FPMI) with 9.22 m long arm cavities and 150 mm diameter (3.29 kg) silicon mirrors. One interferometer will be operating at a cryogenic temperature of 10-15 K with 1550 nm optics, and one at a temperature of 123 K with 2090 nm optics. Both these interferometers are folded to have parallel arms, as illustrated in figure 1 (left). This allows to have a full FPMI in one vacuum beam tube with shared input and end mirrors in two vacuum towers hosting the suspension systems.

The advantage of this implementation is that it enables a simultaneous operation of both interferometer configurations with the construction of only one vacuum system, which can subsequently be used in the future to host one large FPMI with more heavy test masses. The disadvantage is that it requires more complex mirror suspension chains, as two test masses will need to share the same pre-isolation stage. In figure 1 (right) a projected displacement sensitivity spectrum is shown, for an interferometer with 1550 nm laser optics and 18 K temperature, indicating the contributions of various noise sources [2]. The target sensitivity of ETpathfinder is 10^{-18} m/$\sqrt{\text{Hz}}$ at a frequency of 10 Hz.

The project started in 2019 with 7 founding institutes from The Netherlands and Belgium. It is located in Maastricht (NL) and received 14.5M euro funding from Interreg Vlaanderen-Nederland to initiate the detector construction. In 2025 24 partners contribute to the collaboration and several local governments support the ETpathfinder experiment. In summer 2021 the large cleanroom was constructed, and in spring 2024 the majority of the vacuum towers and beam pipes were installed.

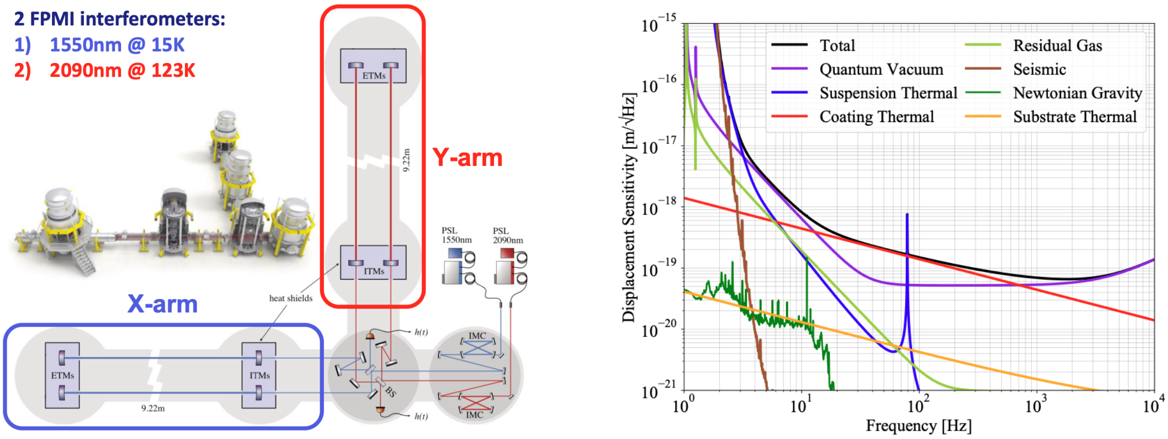

Figure 1: Schematic of the full ETpathfinder detector layout (left) indicating the two folded FPMI in their vacuum arms, and a displacement sensitivity plot (right) of the FPMI using 1550 nm optics at a temperature of 18 K. [2]

2 Seismic isolation and data acquisition

In the first half of 2025 a first suspension tower, the beam splitter tower (BST), was fully constructed and pre-commissioned as shown in figure 2. This suspension consists of an inverted pendulum pre-isolator stage combined with a triple pendulum and three Geometric Anti-Spring (GAS) filters to damp both horizontal and vertical oscillations. At the bottom an optical bench is suspended through a single wire. This bench will host 4 triple-suspension cages, modelled after Advanced LIGO's HRTS design [3], that provide additional damping for the key optical elements (e.g. beam splitter). To enable the inertial damping and bench angular local control the suspension is equipped with combined Linear Variable Differential Transformer (LVDT) + Voice Coil (VC) sensors and actuators, triaxial seismometers, and vertical LVDT's in the GAS filters. During the pre-commissioning of the BST all sensors were successfully calibrated and target noise levels (1 nm/$\sqrt{\text{Hz}}$) were reached within the dynamic ranges. In addition, first in-air tests were done showing a stable operation of the inertial damping and bench angular degrees of freedom. Further detailed characterisations and loop optimisations will be performed in-vacuum throughout 2025.

The necessary computing infrastructure and data acquisition system is set up, including remote access to efficiently analyse raw data produced by the BST. The hardware used is the same as in Advanced Virgo+ [4], developed by Laboratoire d'Annecy De Physique Des Particules (LAPP), and utilises ADC, DAC mezzanines together with so called real-time PC's to process and store data. It is in active use for R&D and commissioning running DataDisplay on the Rocky 9 Unix OS, which is an example where ETpathfinder serves as software testbed before it is deployed at Virgo. Next steps include a set up of detector monitoring and alarms, to continue the data acquisition installation to operate a future full interferometer, and a test of the White Rabbit timing distribution in coming months.

3 Vacuum and cryogenics

The ultra-high vacuum system of ETpathfinder [5] that contains the two interferometers has a volume of 170 m^3 with a target pressure of 10^{-9} mbar. The majority of the system is installed and in operation. Initial tests and validation of the programmable logic controller (PLC) system are in progress. In May 2025 one of the vacuum system arms (North) was successfully pumped down while all procedures were tested.

The cryogenics system needs to be able to provide vibration-free cooling of the suspended silicon mirrors. To achieve this two different techniques will be used depending on temperature: 1) in the 123 K interferometer a radiative cooling system with Liquid Nitrogen (LN2) will be installed to minimise the thermal expansion of silicon; 2) in the 10 K interferometer a sorption cooling technique [6] will be used to minimise the thermal noise in the mirror and coating. For the latter a combination of sorption-based compressors and Joule-Thomson cold stages will be employed. It will have a kickstarter that circulates cold He for the initial cool-down phase with a mechanical cryocooler that will be turned off during science mode, and a separate compressor tower that contains the sorption cooler for science mode cooling. This 10 K zero-vibration sorption cryocooler is being developed by an industrial consortium (Demcon Kryoz, Cooll) with the University of Twente. The requirements imply a cooling power of 50 mW at temperature of 8 K, induced vibration levels below 32 nm, and a cooldown time of less than 4 weeks. The technical design and PLC control have been largely finalised, and the aim is to deliver a full cryocooler system by the end of 2026 and install it in the ETpathfinder 10 K arm.

4 Optics

Already two silicon mirrors are produced by Zeiss according to the full specifications, and the provided surface map data is currently being studied. To further check the surface quality of the cutting and polishing steps a dummy substrate polished by Zeiss was sent to the Laboratoire des Matériaux Avancés (LMA) in France where everything is now ready to start surface absorption measurements. In parallel, a first temperature-dependent measurement of the mechanical loss of silicon samples was performed in Maastricht showing an expected low loss, and clear loss dip around 120 K [7]. In addition, a first birefringence measurement of two silicon samples grown by IKZ–Berlin was performed by the Università Di Ferrara showing a very low birefringence compatible with a requirement of $\Delta n < 10^{-8}$ [8].

A pre-stabilised 1550 nm laser system developed by AEI Hannover arrived in April 2024, and is currently in operation in the laser corner of the ETpathfinder cleanroom with first measurements of the power and frequency stabilisation ongoing.

Figure 2: Picture of the constructed BST suspension of ETpathfinder located in the cleanroom outside the vacuum system.

5 Summary and outlook

The ETpathfinder experiment reached an important milestone in summer 2025, namely the successful installation and commissioning of a first bench suspension tower. With this the collaboration also enters its first commissioning and experimental phase. The available seismic isolation system can be further characterised, and first in-vacuum suspended bench experiments of the input mode cleaner and a novel 3D cryogenic active vibration isolator [9] are being prepared. In the near future the installed beam splitter tower will be hoisted into the vacuum tower and fully commissioned, while in parallel the installation of the injection tower will be started. By the end of 2026 the aim is to provide one installed 10K interferometer arm with available mirror towers containing the vibration free sorption cryocooling.

6 Acknowledgements

The ETpathfinder project in Maastricht is funded by Interreg Vlaanderen-Nederland, the province of Dutch Limburg, the province of Antwerp, the Flemish Government, the province of North Brabant, the Smart Hub Flemish Brabant, the Dutch Ministry of Economic Affairs, the Dutch Ministry of Education, Culture and Science, and by own funding of the involved partners. In addition the ETpathfinder team acknowledges support from the European Research Council (ERC), the Dutch Research Council (NWO), the Research Foundation Flanders (FWO), the German Research Foundation (DFG), Spanish MICINN, the CERCA program of the Generalitat de Catalunya and the Dutch National Growth Fund (NGF).

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