# Time transformations, anisotropy and analogue transformation elasticity

## Executive Summary

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**Date:** 30/06/2014

**ACT research category:** Fundamental Physics

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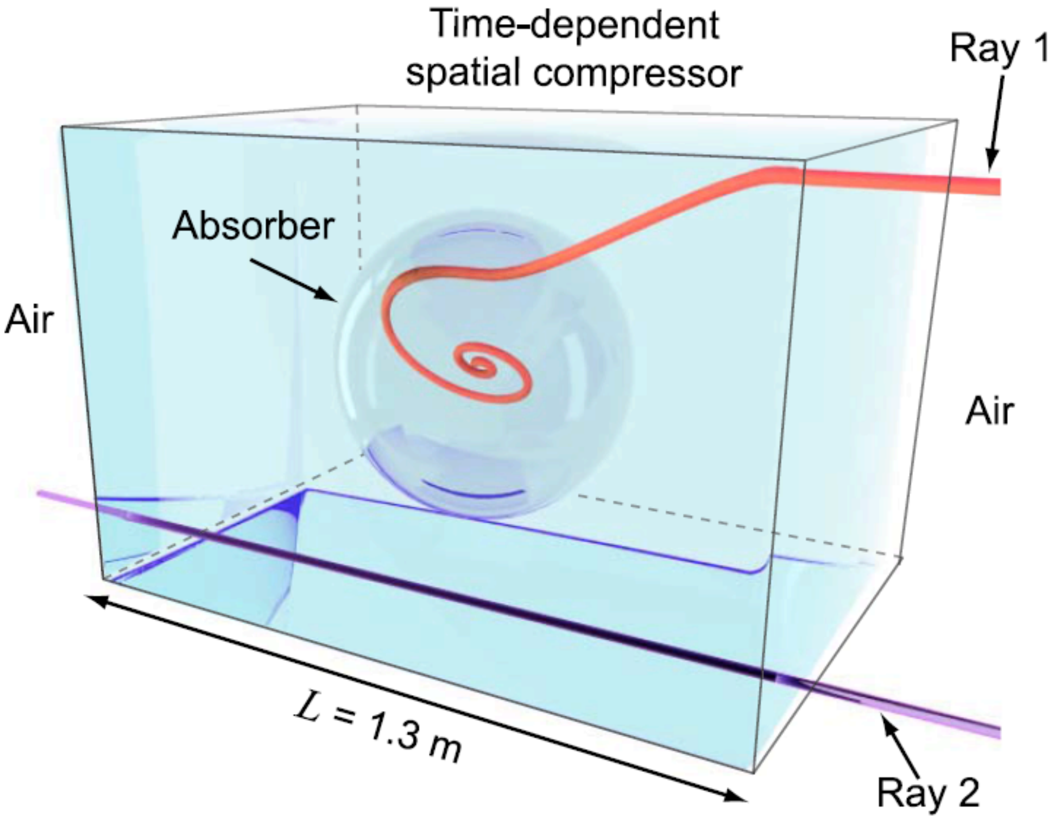
**Ariadna ID:** 11-1301b CCN
**Ariadna study type:** Standard
**Contract Number**: 4000104572/12/NL/KML

Available on the ACT website
http://www.esa.int/act

**Picture:**




**Motivation:**
In the initial project (Ariadna ID: 11-1301b) the tools of relativistic gravitation and analogue gravity were used to generalize the transformational paradigm for metamaterials. The new "analogue transformation" method proved to be a very powerful approach to design metamaterials that are impossible to obtain in other ways. However, the new transformation method was tested only for spatial and isotropic transformations in acoustics. In this project, we aimed at extending this method to include anisotropy and general spacetime transformations in acoustics, as well as towards the construction of a so-called "analogue transformation elasticity". These new techniques allow a completely new level of control of vibrations in solids. Their application offers a theoretical guide to the construction of a new generation of shielding and damping devices that promise applications in the damage control of payloads during the launch phase.

**Methodology:**
The results of the first part of the report were achieved using transformational techniques combined with the tools of analogue gravity and homogenization techniques. The first one was used to be able to implement time transformations in the transformation acoustics whilst the second one considered non-isotropic transformations in both static and moving backgrounds. The methods of elasticity theory in anisotropic media, seismology, and more specific recent research on the elastic properties of composite materials have been used in the second part of

the report. They helped to uncover some (so-far unknown) aspects of elasticity that need to be further clarified in order to construct a meaningful transformation approach for elastic waves.

**Results:**

- Development of a novel route (Analogue Transformation Acoustics, ATA) for transformations mixing space and time in acoustics. This kind of transformation is not allowed in Standard Transformation Acoustics (STA)
- Design of novel acoustic devices based on ATA: a frequency shifter, a spacetime cloak, and a spacetime compressor
- Development of a homogenization process for the acoustic velocity potential wave equation. Our finding reveals a different way of tailoring acoustic properties through gradients of the static pressure. In contrast to standard metafluids based on isobaric composites, this alternative kind of metafluids is suitable for the implementation of transformational devices designed via the velocity potential equation
- Identification of the key issues and current roadblocks in the development of a general theory for transformational elasticity, and definition of several possible future strategies

**Publications:**

1. C. García-Meca, S. Carloni, C. Barceló, G. Jannes, J. Sánchez-Dehesa, and A. Martínez, "Analogue transformations in physics and their application to acoustics," *Nature Sci. Rep.* 3, 2009 (2013).
2. C. García-Meca, S. Carloni, C. Barceló, G. Jannes, J. Sánchez-Dehesa, and A. Martínez, "Space-time transformation acoustics," *Wave Motion* 51, 785 (2014).
3. C. García-Meca, S. Carloni, C. Barceló, G. Jannes, J. Sánchez-Dehesa, and A. Martínez, "Analogue transformation acoustics and the compression of spacetime," *Photon. Nanostruct. Fundam. Appl.*, in press.
4. C. García-Meca, S. Carloni, C. Barceló, G. Jannes, J. Sánchez-Dehesa, and A. Martínez, "Transformational acoustic metamaterials based on pressure gradients," under review in *Phys. Rev. B*.

**Highlights:**

We have clarified fundamental differences between the ATA techniques that we have developed and the STA method. This has allowed us to develop spacetime transformations that can only be performed with ATA. We have applied a homogenization process to the velocity potential acoustic wave equation, which has allowed us to design a multilayer structure able to cloak the acoustic velocity potential. About transformation elasticity, we have concluded that the scope of transformational elasticity is vastly broader than originally expected. For instance, the implementation of spacetime transformations would require the temporal control of some of the properties of the metamaterial system so as to lead to (apparent) flows in the metamaterial.