Theoretical cosmology and astroparticle physics

Matti Heikinheimo

University of Helsinki & Helsinki Institute of Physics

August 24, 2026

The scope of the project (plan from 2025)

- This project acts as an umbrella that covers most of the research in theoretical cosmology and astroparticle physics in Finland.
- University of Helsinki (UH) and University of Jyväskylä (JyU).
- Planned budget: 115 k€ annually.
- Project funds will be used to facilitate meetings and seminars that serve this research community.
- Some funds also reserved to cover periods of otherwise missing funding for PhD students, adding flexibility to the operations of the participating research groups.
- One postdoc to be hired at UH for Heikinheimo.
- Contributions to personnel costs for Cosmology data center to facilitate LISA-activities.

The scope of the project (plan from 2025)

- This project acts as an umbrella that covers most of the research in theoretical cosmology and astroparticle physics in Finland.
- University of Helsinki (UH) and University of Jyväskylä (JyU).
- Planned budget: 115 k€ annually.
- Project funds will be used to facilitate meetings and seminars that serve this research community.
  - Weekly cosmology seminars, Tampere cosmology day, particle physics day.
- Some funds also reserved to cover periods of otherwise missing funding for PhD students, adding flexibility to the operations of the participating research groups.
- One postdoc to be hired at UH for Heikinheimo.
- Contributions to personnel costs for Cosmology data center to facilitate LISA-activities.

The scope of the project (plan from 2025)

- This project acts as an umbrella that covers most of the research in theoretical cosmology and astroparticle physics in Finland.
- University of Helsinki (UH) and University of Jyväskylä (JyU).
- Planned budget: 115 k€ annually.
- Project funds will be used to facilitate meetings and seminars that serve this research community.
- Some funds also reserved to cover periods of otherwise missing funding for PhD students, adding flexibility to the operations of the participating research groups.
  - Covered salaries for PhD students Hanna Lempiäinen (supervisors M.H/Kimmo Tuominen/Risto Paatelainen) and Olli Väisänen (supervisor Kimmo Kainulainen) over gaps in stipend funding.
  - Hired two new PhD students (Jan Loder (Axions) and Jeff Schymiczek (COSINUS)) to the group as of this fall semester, cover from the project untill other funding found.
- One postdoc to be hired at UH for Heikinheimo.
- Contributions to personnel costs for Cosmology data center to facilitate LISA-activities.

The scope of the project (plan from 2025)

- This project acts as an umbrella that covers most of the research in theoretical cosmology and astroparticle physics in Finland.
- University of Helsinki (UH) and University of Jyväskylä (JyU).
- Planned budget: 115 k€ annually.
- Project funds will be used to facilitate meetings and seminars that serve this research community.
- Some funds also reserved to cover periods of otherwise missing funding for PhD students, adding flexibility to the operations of the participating research groups.
- One postdoc to be hired at UH for Heikinheimo.
  - Shiuli Chatterjee will start as a postdoc in May 2027, to work on dark matter production/phase space Boltzmann equations.
- Contributions to personnel costs for Cosmology data center to facilitate LISA-activities.

The scope of the project (plan from 2025)

- This project acts as an umbrella that covers most of the research in theoretical cosmology and astroparticle physics in Finland.
- University of Helsinki (UH) and University of Jyväskylä (JyU).
- Planned budget: 115 k€ annually.
- Project funds will be used to facilitate meetings and seminars that serve this research community.
- Some funds also reserved to cover periods of otherwise missing funding for PhD students, adding flexibility to the operations of the participating research groups.
- One postdoc to be hired at UH for Heikinheimo.
- Contributions to personnel costs for Cosmology data center to facilitate LISA-activities.
  - A few months of the salary of Deanna Hooper covered from the project.

Main lines of research pursued in the project

- Inflation and the origin of dark and visible matter
  - This theme covers the research on cosmic inflation, reheating and the mechanisms for producing dark matter and the baryon asymmetry.
  - The participating senior researchers are Matti Heikinheimo (UH), Kimmo Tuominen (UH), Syksy Räsänen (UH), Kimmo Kainulainen (JyU) and Sami Nurmi (JyU).
- Phase transitions and Gravitational waves
  - Numerical simulations of gravitational wave production in first order phase transitions, Participation in the LISA collaboration and the Finnish cosmology data center.
  - Senior researchers David Weir (UH) and Mark Hindmarsh (UH).
- Direct detection of dark matter
  - Theoretical research on phenomenology of low threshold detectors utilized in searches for light DM. For this line of research we recently obtained the research council of Finland project funding for 9/2025-8/2029, worth 983 k€.
  - The COSINUS experiment.
  - Matti Heikinheimo (UH), Kai Nordlund (UH), Kimmo Tuominen (UH).

Main lines of research pursued in the project

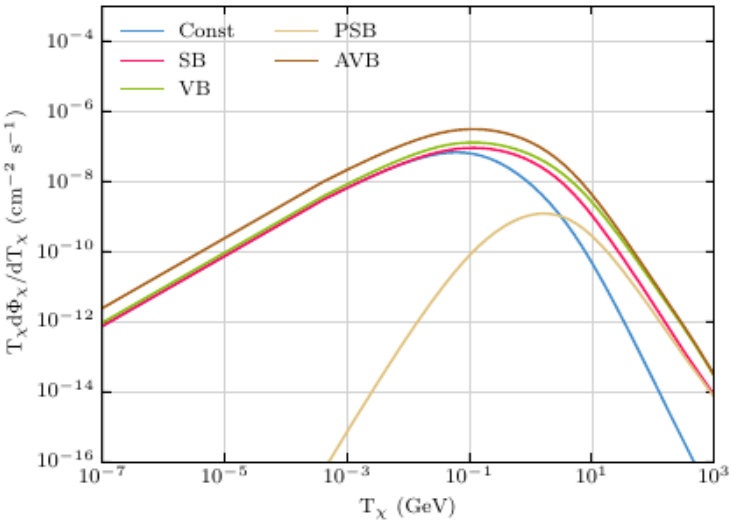
- Inflation and the origin of dark and visible matter
- Phase transitions and Gravitational waves
- Direct detection of dark matter
  - Theoretical research on phenomenology of low threshold detectors utilized in searches for light DM. For this line of research we recently obtained the research council of Finland project funding for 9/2025-8/2029, worth 983 k€.
    - Sebastian Sassi started as a postdoc in September 2025 with M.H.
    - Fanhao Kong (PhD student) and Federico Ledda (Postdoc) started in computational materials physics with Kai Nordlund.
  - The COSINUS experiment.
  - Matti Heikinheimo (UH), Kai Nordlund (UH), Kimmo Tuominen (UH).

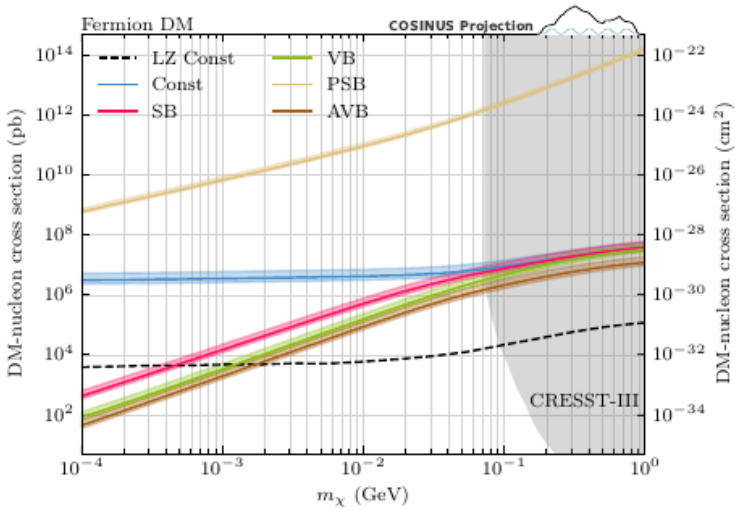
Main lines of research pursued in the project

- Inflation and the origin of dark and visible matter
- Phase transitions and Gravitational waves
- Direct detection of dark matter
  - Theoretical research on phenomenology of low threshold detectors utilized in searches for light DM. For this line of research we recently obtained the research council of Finland project funding for 9/2025-8/2029, worth 983 k€.
  - The COSINUS experiment.
    - Experimental facility at LNGS completed, first measurements with a NaI module performed there. The science run to begin within 2026.
    - Currently also performing measurements to understand the low energy excess, along the main theme of the RCF grant.
  - Matti Heikinheimo (UH), Kai Nordlund (UH), Kimmo Tuominen (UH).

Selected recent results

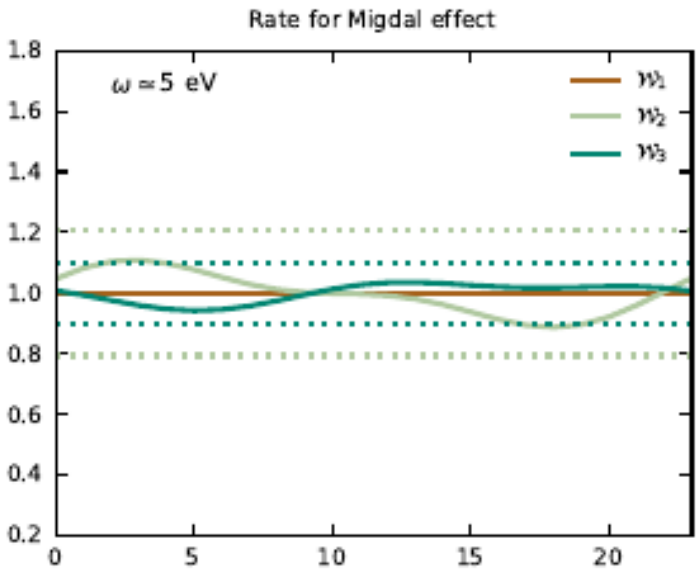
- Analysis on the sensitivity of the COSINUS experiment for cosmic ray boosted DM, Arxiv:2603.22971: We present a catalogue of simplified-model based energy-dependent scattering cross sections and the resulting boosted DM event rates in COSINUS, with the projected exclusion limits.
- Corresponding authors: Niklas Zimmermann, M.H.

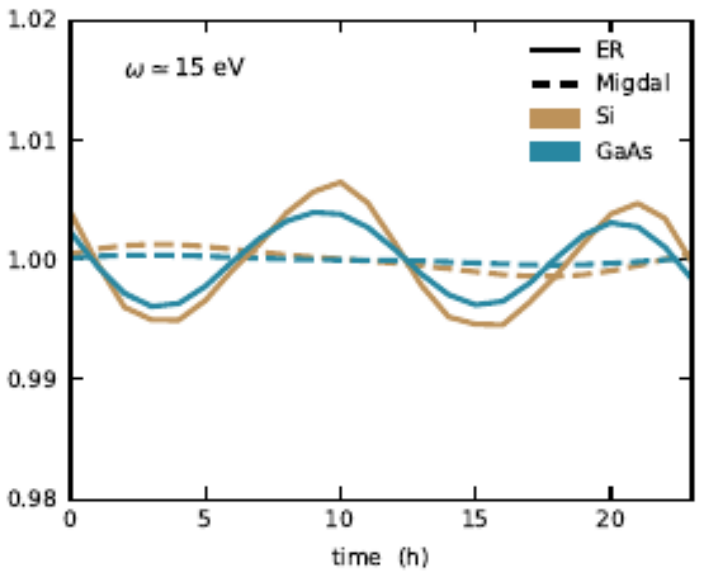




Selected recent results

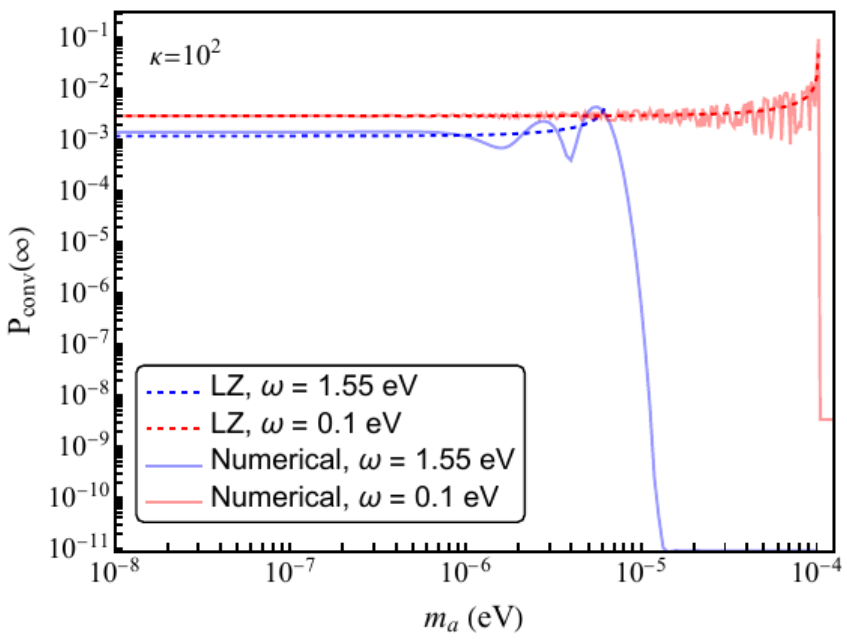
- Developed a formalism and computational implementation for directional dependence of the Migdal effect (Electron excitation due to nuclear recoil event) in solid state DM detectors, Arxiv:2607.06005.
- Work done in collaboration with the theoretical materials physics group at the University of L'Aquila, Italy (Prof. Gianni Profeta).

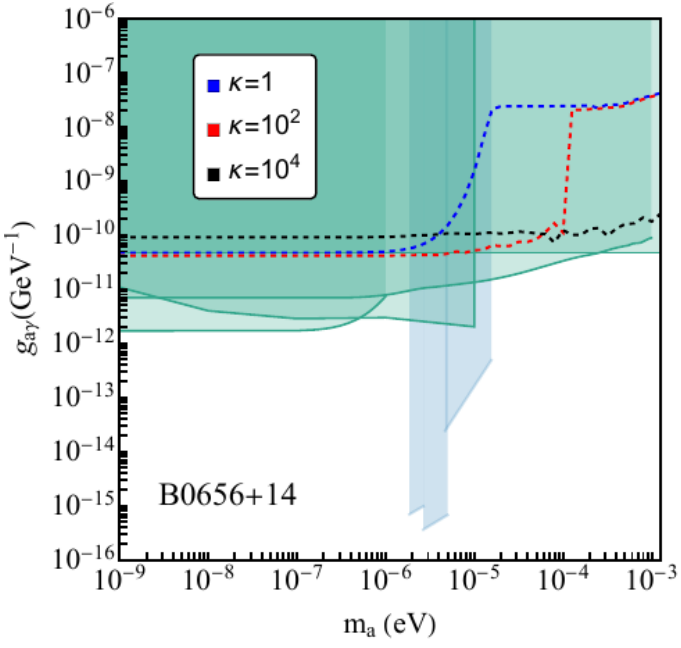




Selected recent results

- Analysis on the applicability of the Landau-Zener formula in axion-photon conversion in neutron star magnetospheres, Arxiv:2606.31476.
- We formulate validity conditions for the LZ-formula, commonly used in the literature, and show that in many realistic scenarios the formula is not applicable, leading to overestimated bounds for axions.





Conclusions

- The purpose of the project is to act as an umbrella, facilitating networking and collaboration within the Finnish cosmology and astroparticle theory research.
- The salaries paid from the project will contribute to the LISA activities via the cosmology data center, and to the direct detection and dark matter theory research of the PI Heikinheimo.
- The direct detection project supports our participation in the COSINUS experiment, aiming to begin the first science run within this year.