LIGO

Working Group 2: Cosmology & Dark Matter

Report for the 3rd General Meeting

María Benito, Marco Gorghetto, Mathieu Kaltschmidt & Edoardo Vitagliano

3rd General Meeting
Sofia, September 11/12th 2025

G. Pierobon

DESI

PLANCK

Departamento de Física Teórica
Universidad Zaragoza

Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza

GOBIERNO DE ARAGON

COSMIC WISPERS
CA21106

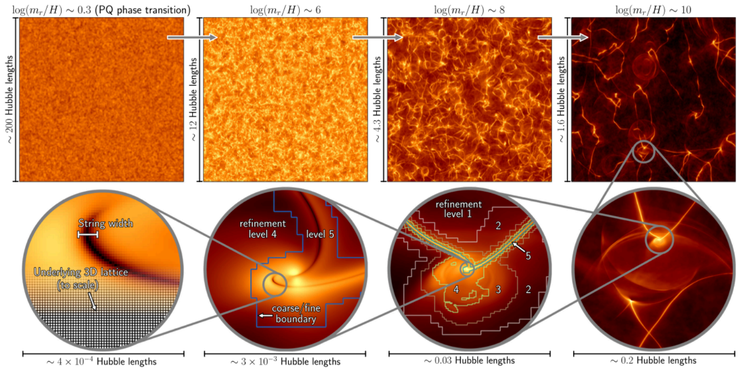
cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

WG2 Overview

- WISPs are compelling **dark matter** candidates!
- From the Cosmology & Dark Matter side, there are plenty of interesting questions to answer:
    - What are the relevant **production mechanisms**? Are there new ideas & new detection opportunities? (WG1, WG3)
    - If the QCD axion is the DM, can we pin down conclusively its **mass** and **couplings**? (WG1, WG3, WG4)
    - What is the WISP DM structure (MCs, axion stars) at sub-galactic scales, both for axions and dark photons? (WG3, WG4)
    - Can we predict and detect **gravitational waves**, **dark radiation** and other observables associated to WISPs? (WG4)
    - Can WISPs play the role of **dark energy** or help to understand **cosmological tensions**? (WG1, WG3)

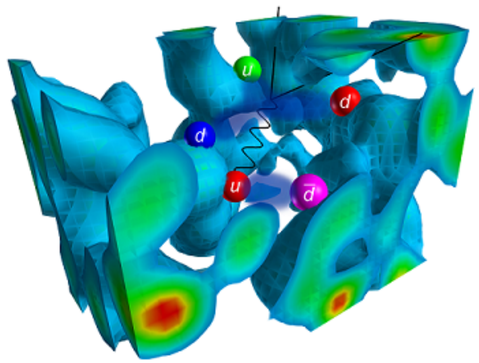
Diverse Range of Topics & Expertise

Phase transitions and topological defects



Benabou et al. [2412.08699]

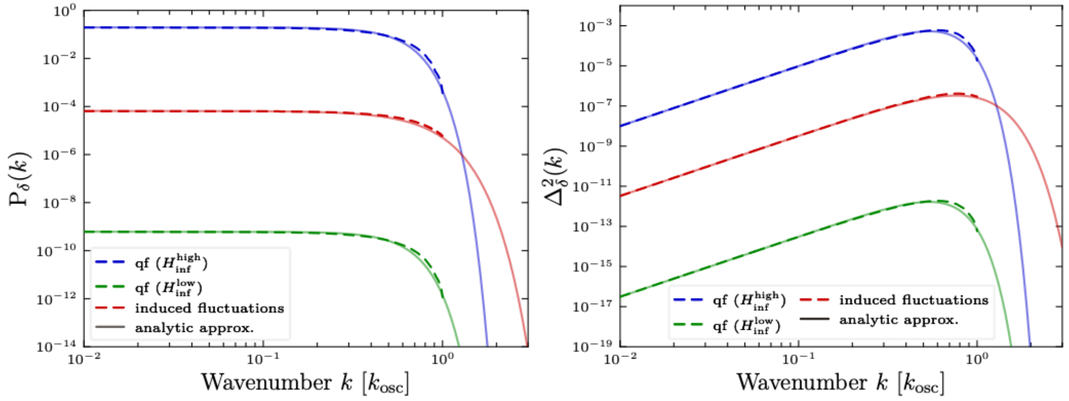
Lattice QCD (e.g. for $m_a(T)$)



Leinweber (Link)

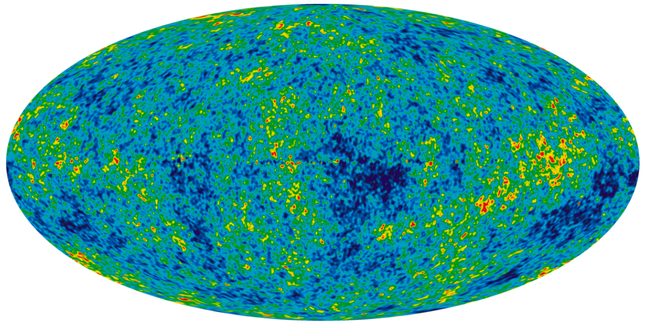
WISP Cosmology

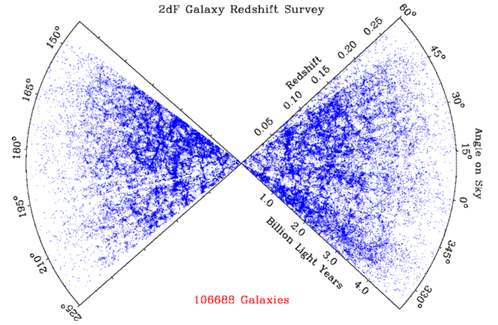
Hot dark matter components, modified power spectra, …



Ayad + Schwarz [2503.05532]

Observational cosmology: CMB, LSS, …





Large Community

- **282 (!) group members** as of September 2025
- Substantial overlap of interests with other WGs (and other research areas)
- Involved in many activities in the last year, more details later!

Co-Leaders:

M. Benito (IAC, Tenerife)

M. Gorghetto (DESY)

M. Kaltschmidt (Zaragoza)

E. Vitagliano (Padua)

Our Activities - 2025 Overview

1. **Working group Meeting** 13-14 Feb 2025, Heidelberg

   Speakers: M. Hindmarsh, V. Vaskonen

2. **Online Workshop** “Dynamical Tracers of the Nature of Dark Matter”

   Co-Organised by M. Benito, more details later

3. **Brain storming Meeting** 3 Apr 2025, Online

   Speakers: P. Delgado, L. Ubaldi

4. **3rd General Meeting** 9-12 Sep 2025, Sofia

   Plenary: H. Kim, K. Rogers, E. Di Valentino, K. Blum

   Parallel (together with WG3): A. Macdonald, A. Lenoci, M. Galaverni, M. Benito, T. Sassi, C. Garcia Cely

5. **3rd Training School** 16-19 Jun 2025, Annecy

   Lectures on “Ultralight dark matter”

   Lecturer: E. Ferreira (IPMU Tokyo). Trainer: A. Eberhardt (IPMU Tokyo)


Feb 2025, Heidelberg

WG2 Online Meetings

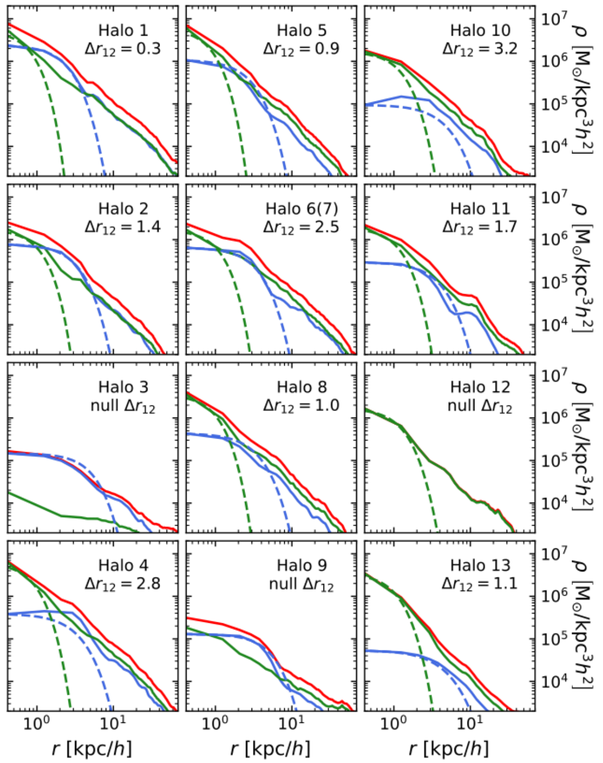
- We try to organise a meeting ~ every last Friday of the month,

  30-minute talk + discussion

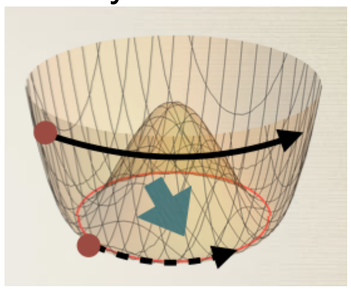
- Details: https://indico.desy.de/event/48394/overview
- Recent meetings:

1. Experimental targets for dark photon dark matter (**D. Cyncynates**)
2. New avenues to probe the ultralight end of Dark Matter (**J. Urrutia**)
3. Wave DM around Black Holes (**J. Aurrekoetxea**)
4. Axion Acoustic Misalignment Mechanism (**R. Co**)
5. Diverse dark matter haloes in Two-field Fuzzy Dark Matter (**Hoang Nhan Luu)**
6. Impact of Adiabatic Fluctuations on the Power Spectrum of QCD Axion DM (**A. Ayad**)

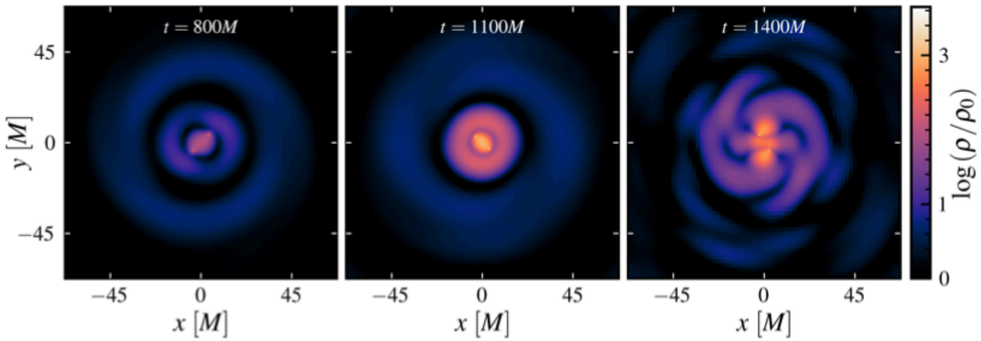
Hoang Nhan Luu

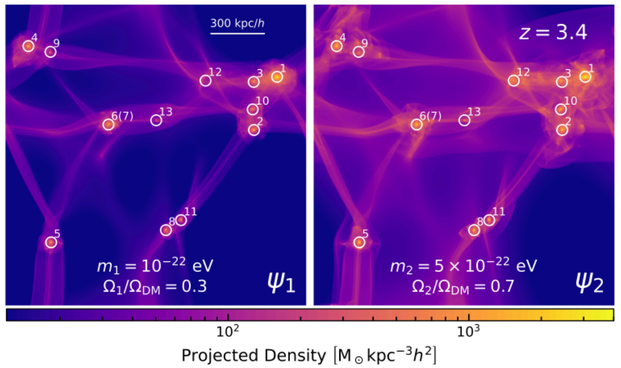


Raymond Co



Josu Aurrekoetxea





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2. October 2025, 14.00 CET

Hoang Nhan Luu

Raymond Co

Josu Aurrekoetxea

WG2 Contribution to “Whispered Tutorials”

Within the YRC, the idea of the “Whispered Tutorials” was developed to extend the standard activities. The idea is to find experts within our community that present pedagogical overviews/lectures of various topics related to the COST action. So far we had four tutorials:

1. **The QCD Axion Potential**, May 2024

   Speaker: C. Eröncel

2. **Axions from String Theory and their EFT**, October 2024

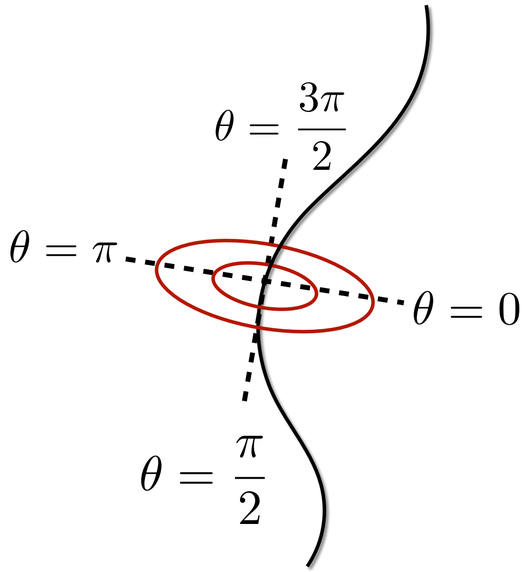
   Speaker: N. Righi

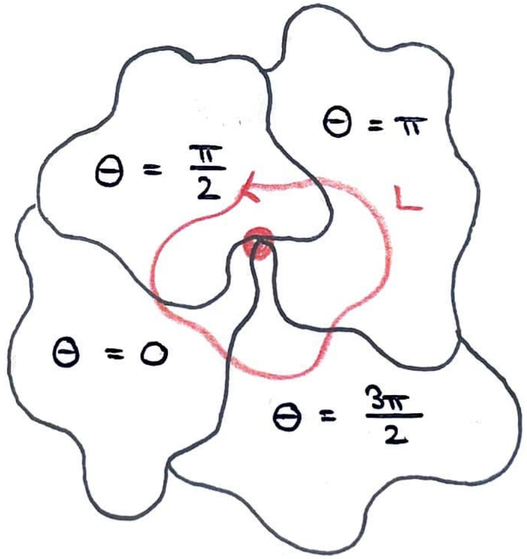
3. **Plasma Haloscopes (ALPHA)**, 2024

   Speaker: A. Millar

4. **Topological Defects & Axion Strings**, March 2025

   Speakers: A. Drew & M. Kaltschmidt





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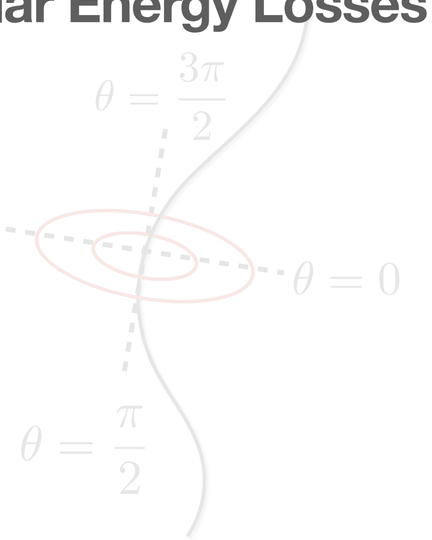
One of the central WG2 topics, but not the only one .. maybe you are interested in presenting something?

Some Examples:

- **Supernova Axions**
- **Stellar Energy Losses**
- **…?**



Reach out to the organisers:
philip.soerensen@pd.infn.it
amedeomaria.favitta@unipa.it
luca.caloni@unife.it

WG2 Chapter for the White Paper

- **Editors:** A. Drew, S. Gasparotto, M. Gorghetto, M. Kaltschmidt, E. Vitagliano

Authors

- **Contribution to European strategy for Particle Physics has been submitted!**

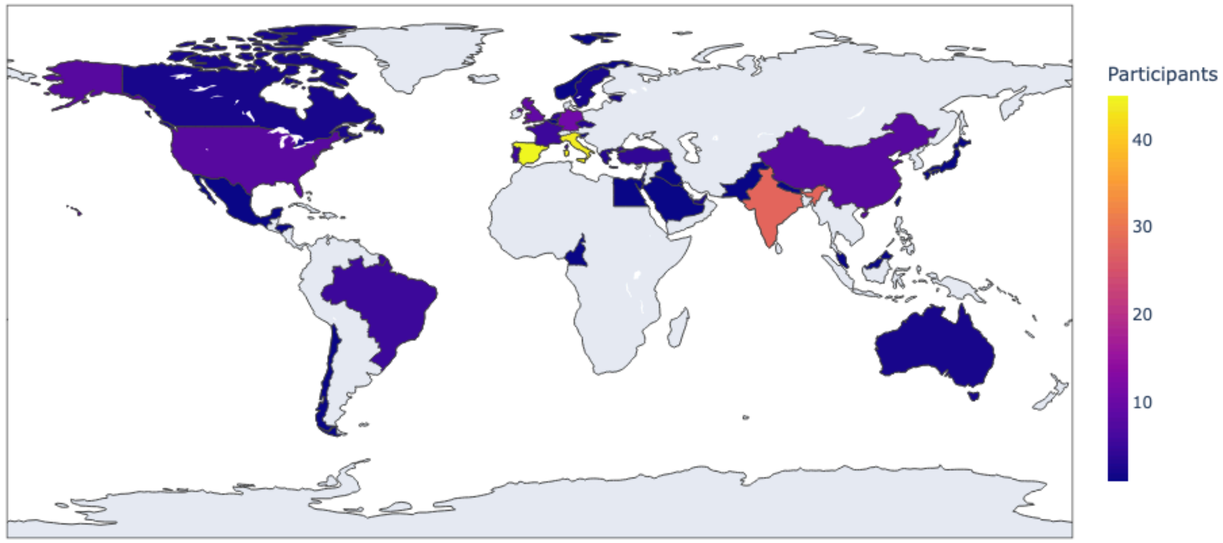
Example of past Activity

We (together with WG3) organized a 2-day online workshop in February 2025.

Details: https://indico.ict.inaf.it/event/2845/overview

Videos of the talks: YouTube I, YouTube II

3 invited talks per day (30 min each)
+
1.5 h discussion session

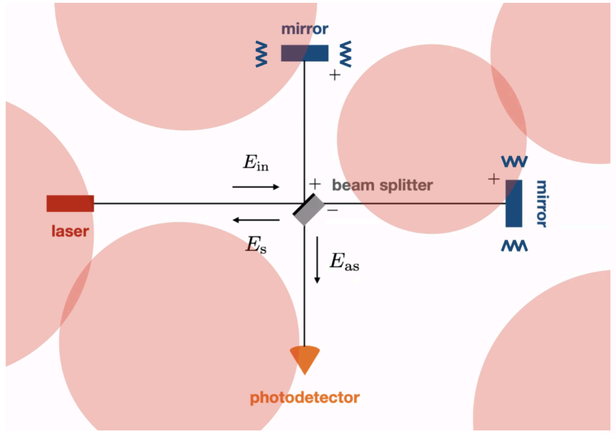


The event attracted **274 registered participants** from **30 countries**, with peak attendance of 101 participants/session.

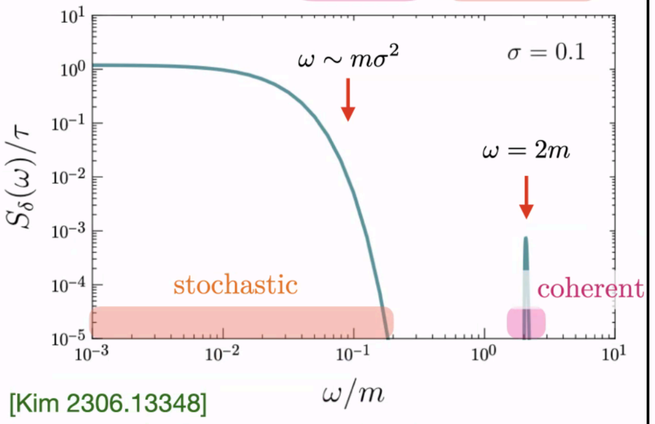
Online Discussion Platform: Padlet

This General Meeting

H. Kim:
New Opportunities for Ultralight DM Searches with Stochastic Fluctuations

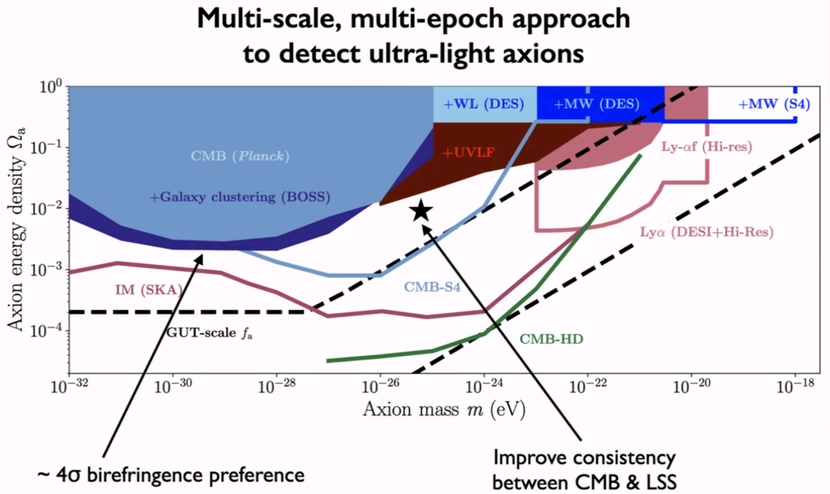


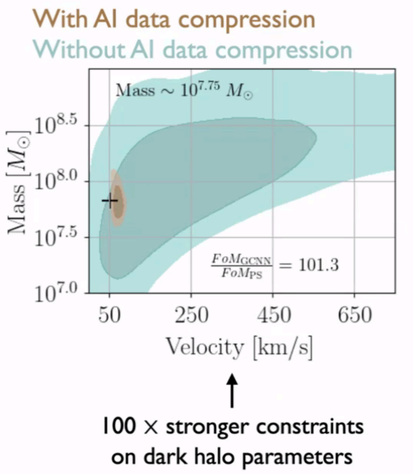
$$S_\delta(\omega) = \tau[\sigma^4 A_\delta(\omega) + B_\delta(\omega)]$$



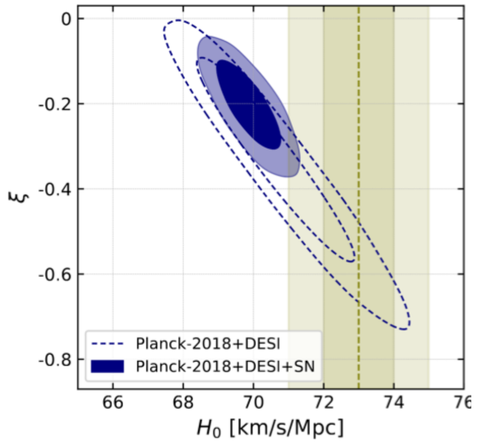
[Kim 2306.13348]

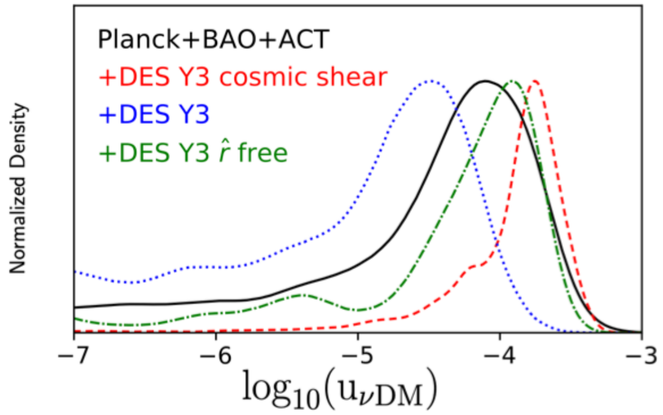
K. Rogers:
Cosmological tests of WISP Dark Matter and Dark Energy



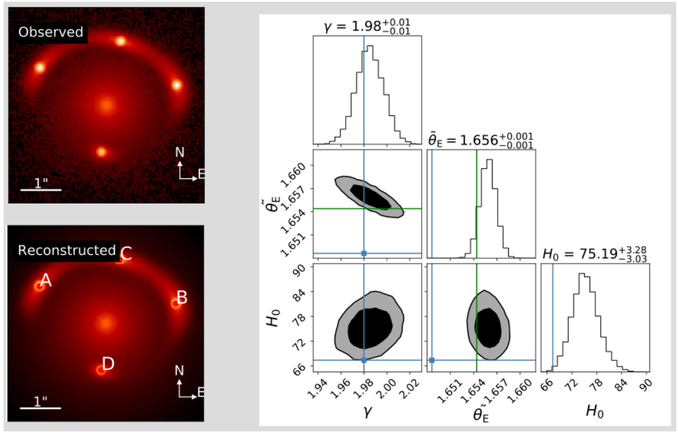


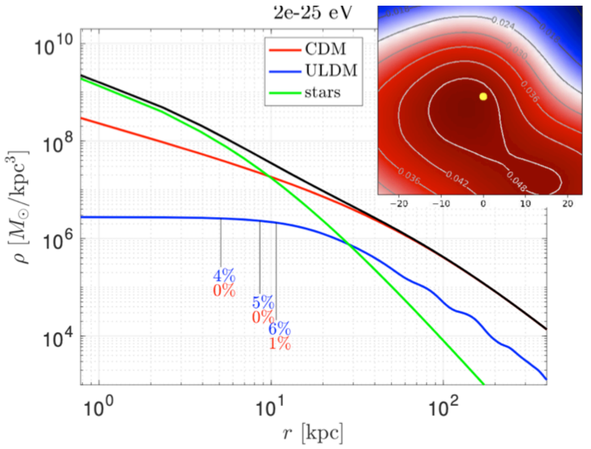
E. Di Valentino
Cracks in the Standard Cosmological Model:
Anomalies, Tensions, and Hints of New Physics





K. Blum:
Gravitational probes of ultralight dark matter





Short-Term Scientific Missions - 2025

Christopher Eckner (WG 2, 3)
STSM: Slovenia —> France

Alessandro Lella (WG 2, 3)
STSM: Italy —> France

Oindrila Ghosh (WG 2, 3, 5)
STSM: Sweden —> Spain

Alessandro Lenoci (WG 2, 3)
STSM: Israel —> France

Oleksii Sokoliuk (WG 2)
STSM: Ukraine —> UK

Pierros Ntelis (WG 1, 2, 5)
YRIC: France —> Canada (DSU2025)

Fostering new interconnections between WGs, exploring new ideas

Room for improvements

No gender balance

Some Grantees don’t show up in any of Action’s activities

Some concrete STSM Examples

Gravitational wave astrophysics ⟷ Particle physics research

Oindrila Ghosh (postdoc @ Sweden) visited IFIC (Valencia) to explore axion production in stellar objects and potential detectability with gravitational waves

Cosmic chemical evolution ⟷ WISPs DM cosmology

Oleksii Sokoliuk (research scholar @ Ukraine) visited Cambridge (UK) to develop a semi-analytical model of the metal content in the early and late universe

DM particle parameter space ⟷ WISPs DM cosmology

Alessandro Lenoci (postdoc @ Israel) visited Padova (Italy) to investigate the phenomenology of scalar dark matter with an axion portal to the Standard Model

Still some things to do in the last year …

T2.1: Perform accurate numerical simulations to obtain precise predictions of axion and WISP DM relic abundance.

- Subtask 2.1.1: Perform additional simulations of the evolution of the string network to obtain the number density of QCD axions that contributes to DM.
- Subtask 2.1.2: Perform QCD lattice simulations at the QCD phase transition to improve the knowledge of the temperature dependence of the axion mass, which affects the relic abundance.
- Subtask 2.1.3: Perform lattice QCD simulation to determine the axion-pion thermalization rate and determine a reliable hot-dark matter axion bound.
- Subtask 2.1.4: Compile a list of WISP DM candidates and their production mechanisms, in order to identify calculations required to improve relic abundance predictions, and also to clarify whether the WISP-DM parameter space is fully explored.

T2.2: Study the formation of Large Scale Structures (LSSs) in various WISP scenarios.

- Subtask 2.2.1: Perform numerical studies of the growth of inhomogeneities in QCD axion DM, from the QCD phase transition onwards.
- Subtask 2.2.2: Study the formation of Large Scale Structures (LSSs) in various WISP scenarios and work to obtain a public code that could describe ALPs and QCD axions impact on LSS.

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- Latest generation of simulation papers published by different members of the COST action
- Extensive Overviews in the White Paper
- Multiple STSMs dedicated for directly addressing these central questions of WG2

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- Same here, many Cosmic WISPers related collaborations and new results
- Also covered in White Paper

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Code exists already!

Please reach out to David Mota (d.f.mota@astro.uio.no) if you are interested to collaborate

WG2 - Honorable Mention

T2.1: Perform accurate numerical simulations to obtain precise predictions of axion and WISP DM relic abundance.

- Subtask 2.1.1: Perform additional simulations of the evolution of the string network to obtain

Cosmology of axion dark matter #11

Ciaran A.J. O'Hare (Sydney U.) (Mar 26, 2024)

Published in: *PoS* COSMICWISPers (2024) 040 • Contribution to: COSMICWISPers, 040 • e-Print: 2403.17697 [hep-ph]

pdf DOI cite claim reference search 121 citations

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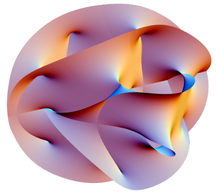
The road ahead — developing further connections



What models are motivated from fundamental principles?

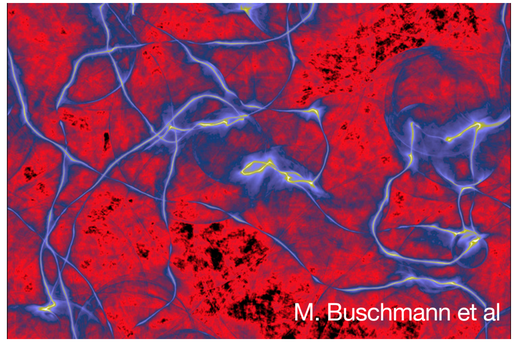
WG1: model building

What fundamental properties can we constrain from observations?

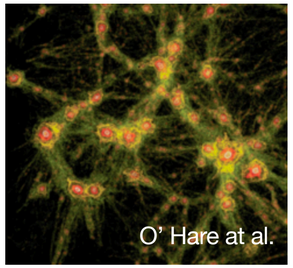
WG2: cosmology

Making nice pictures!

WG5: Outreach



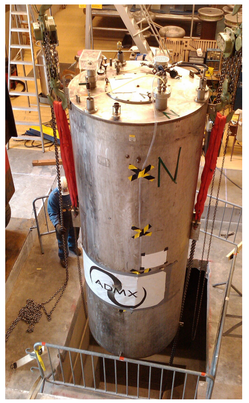
WG3: Astrophysics



Can we infer WISP DM substructure and other effects on **astrophysical bounds**?

Can cosmology predict WISP abundance, and **mass**? Feeding into experiments

WG4: Experiments



Discussion Time: Interesting open Questions

- The QCD axion could have a mass $m_a \sim 0.1 \div 0.5 \cdot 10^{-3}$ eV (or even larger!)
  - Are there new experimental ideas for that mass range?
  - What are the main challenges in advancing the relevant numerical simulations?
- For the QCD axion, a number of arguments (including simulations) seem to hint at $f_a \lesssim 10^{10} \div 10^{11}$ GeV.
  - Are there plausible compactification scenarios in String Theory that lead to such values?
- An ~O(1) DM fraction might be made of compact overdense objects, with longer coherence time.
  - How can we use this information to boost experimental searches?
- Can we set *robust* constraints on WISP masses from astro/cosmo observations?
- Is non-interacting, single-field FDM rule out by observations? How well understood are multi-field FDM models? What are the consequences of such models?
- Is there a minimal parameterization of WISP DM that is directly usable in data-driven pipelines?
- (How) can WISPs help to resolve cosmological tensions?
- Is there a minimal way of generating high-frequency GWs from astrophysical processes?