High energy theory:

AstroParticle

Speaker: Marco Peloso

Staff:
Francesco D'Eramo, Antonio Masiero, Marco Peloso, Edoardo Vitagliano

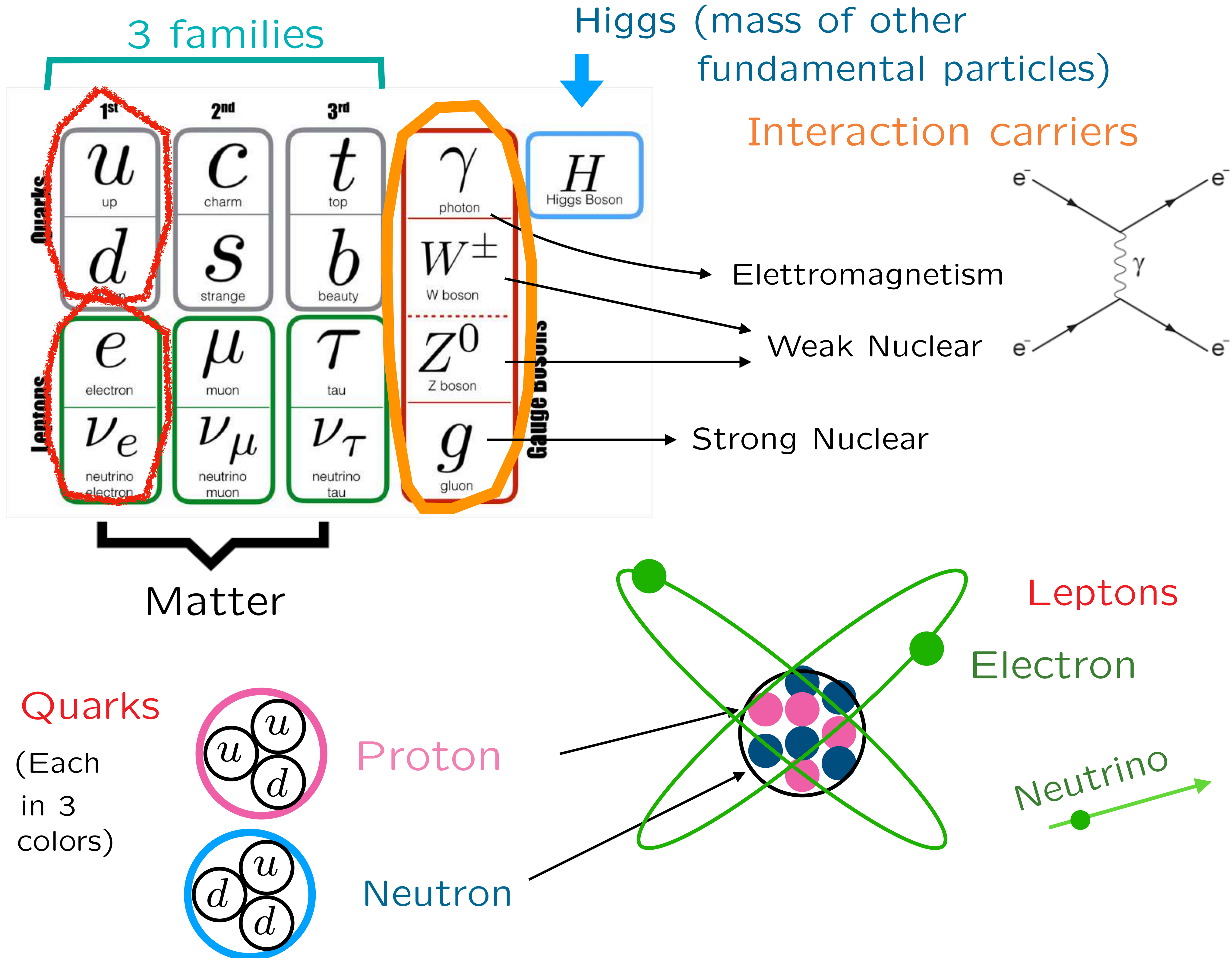
Contacts

Group:

Staff: Francesco D'Eramo, fderamo@pd.infn.it, Office 307
Antonio Masiero, antonio.masiero@pd.infn.it, Office 240
Marco Peloso, *marco.peloso@pd.infn.it, Office 355*
Edoardo Vitagliano, edoardo.vitagliano@unipd.it, Office 307

Postdocs: Jun'ya Kume, Ville Vaskonen,

Ph.D. students: Federico Greco, Tommaso Sassi


3 families
Higgs (mass of other fundamental particles)
Interaction carriers
1st
2nd
3rd
Quarks
u
up
c
charm
t
top
d
s
strange
b
beauty
Leptons
e
electron
μ
muon
τ
tau
ν_e
neutrino electron
ν_μ
neutrino muon
ν_τ
neutrino tau
γ
photon
W±
W boson
Z0
Z boson
g
gluon
Gauge Bosons
H
Higgs Boson
Elettromagnetism
Weak Nuclear
Strong Nuclear
e-
e-
e-
e-
γ
Matter
Leptons
Electron
Quarks
(Each in 3 colors)
u
u
d
Proton
u
d
d
Neutron
Neutrino

Open questions

- Why is gravity so much weaker than the other interactions?

- Why 3 families?
- Why quarks have the observed mass pattern?
- Why antimatter in the universe $\ll$ matter?

?

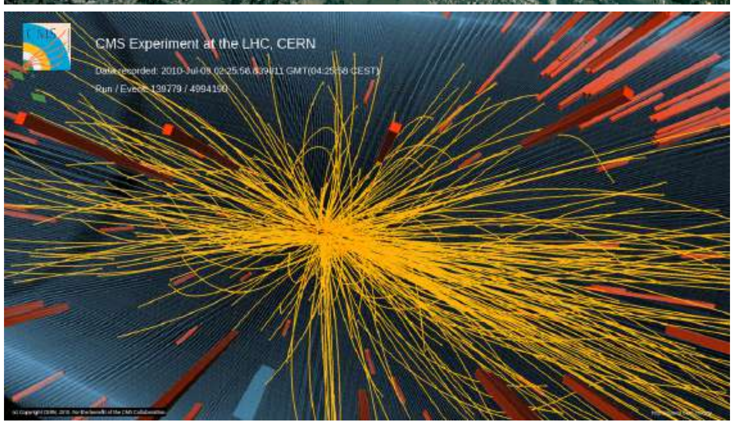
axions?

$$\rho_{\text{visible}} : \rho_{\text{dark matter}} : \rho_{\text{dark energy}} \simeq 0.05 : 0.26 : 0.69$$

- What is dark matter? How was it produced? Why $O\left(\rho_{\text{visible}}\right)$?
- Dark energy = vacuum energy? Why so small? Why $O\left(\rho_{\text{visible}}\right)$?
- Why is the universe so simple? (spatially flat, $\simeq$ homogeneous and isotropic); what are the seeds of galaxies?
- Why are neutrinos so light?
- Why do strong interactions respect CP?

How do we study very massive / very weakly interacting particles?

★ Produce them on Earth

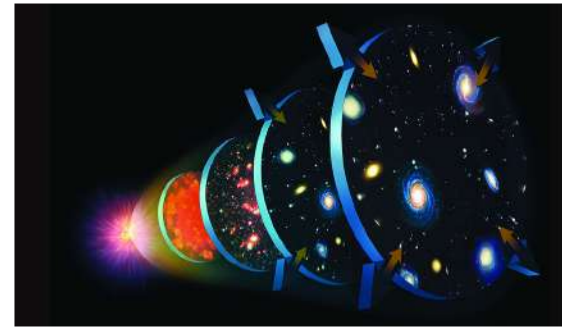


$E_{\text{collision}} \sim \mathrm{O}\,(10\,\text{TeV})$

★ Observe them from the sky

Early universe

$$T \sim \text{MeV}\,\left(\frac{s}{t}\right)^{1/2}$$



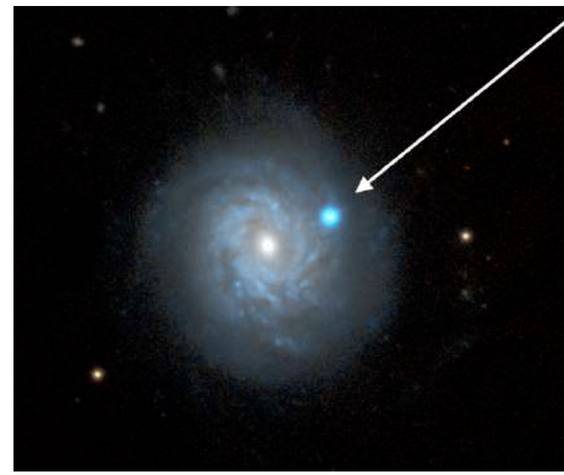
Supernovae

Burst of $\sim 10^{52}\ \ \nu$

in $\mathrm{O}\,(10)$ seconds

with $E = \mathrm{O}\,(10\,\text{MeV})$

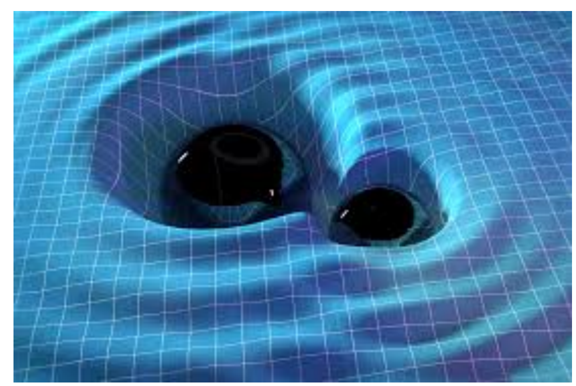
at core-collapse



Gravitational waves

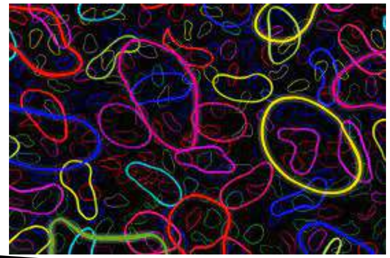
from BH and NS

collisions

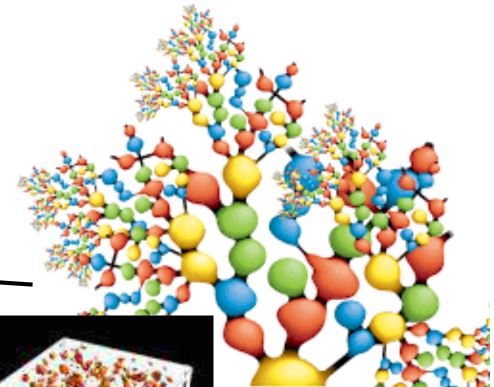


Thermal history and particle processes in the universe

$\sim 10^{-44}$ s — Quantum gravity?

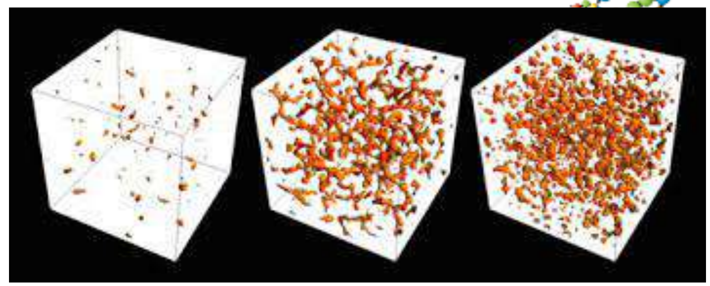


$\sim 10^{-36}$ s — Inflation?



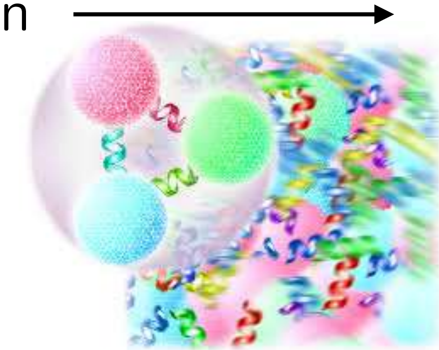
?

Reheating (baryogenesis, dark matter, …)



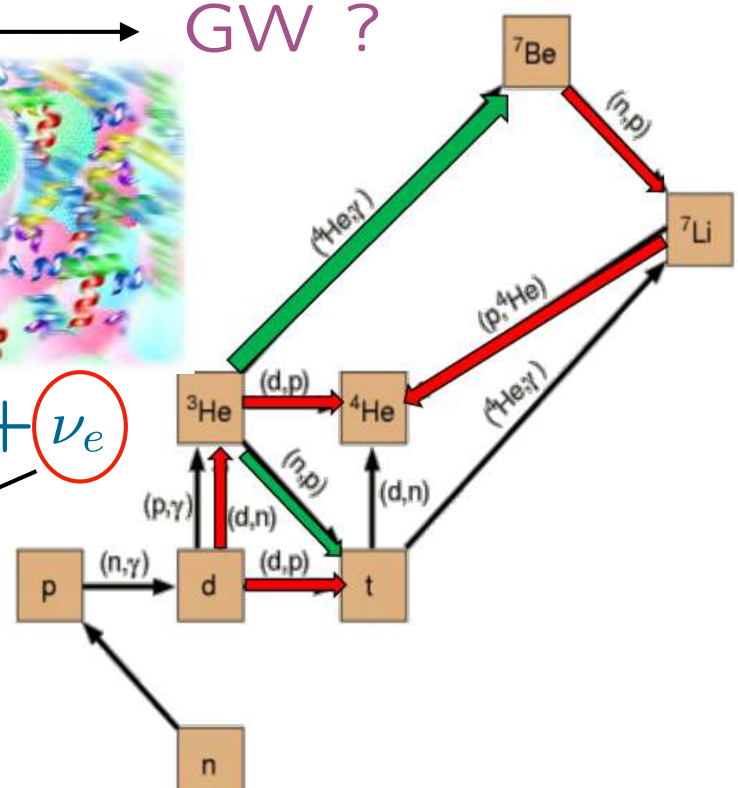
$\sim 10^{-11}$s — Electroweak phase transition → GW ?

$\sim 10^{-5}$s — Quark $\to$ hadron transition



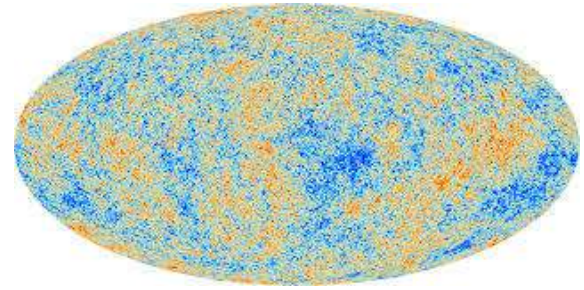
~ 1 s — Neutrino decoupling $\quad p + e \leftrightarrow n + \nu_e$ → us

~ 20 min — Formation of light nuclei

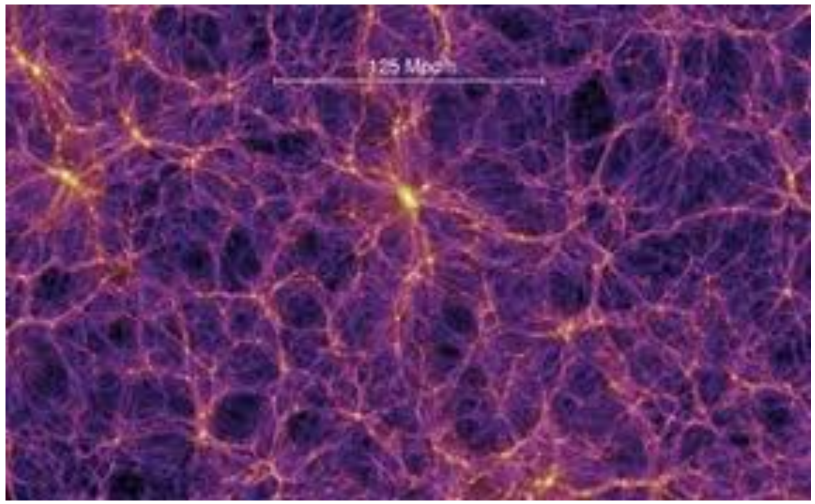


∼ 60 kyr — Matter domination

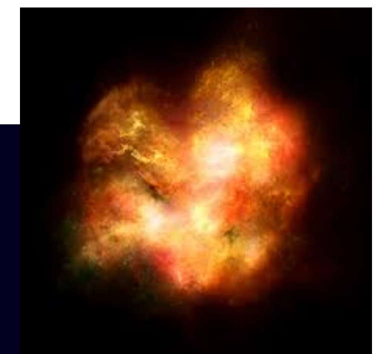
∼ 380 kyr — Atoms formation, universe becomes transparent → CMB



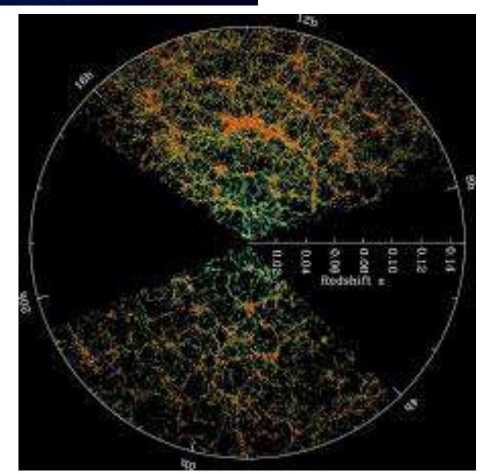
Structure formation



O (100 Myr) — First stars and galaxies



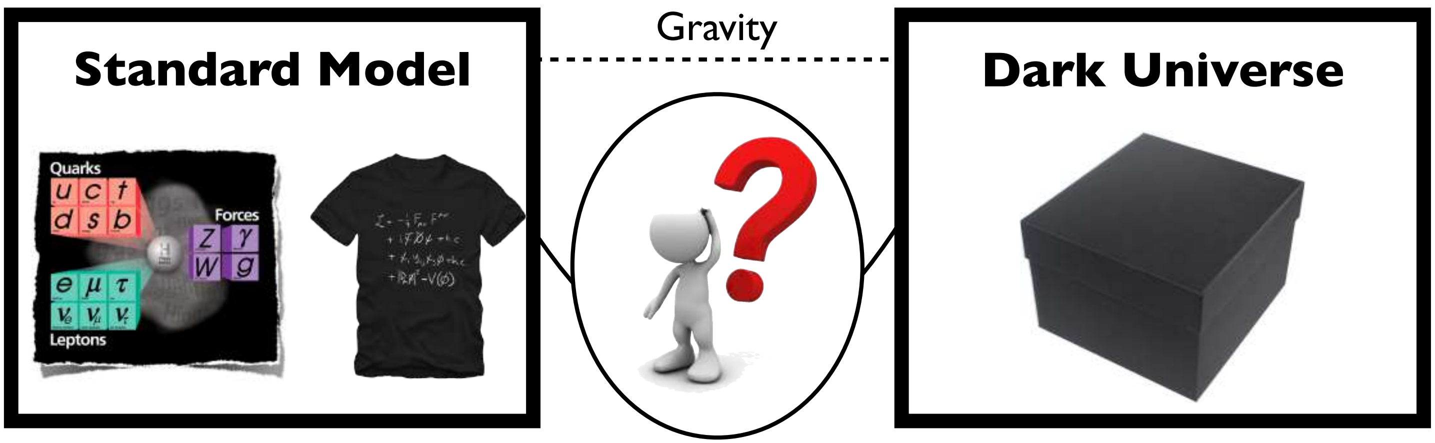
∼ 10 Gyr — Dark energy domination

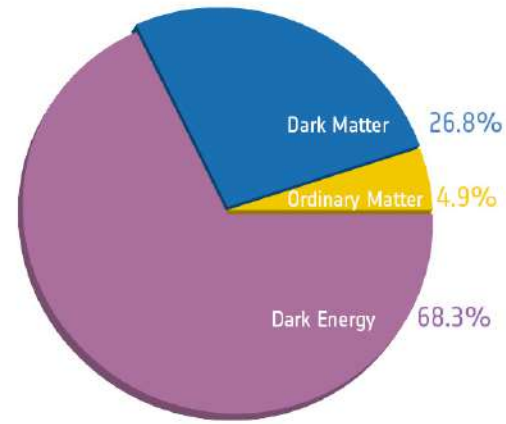


∼ 13.7 Gyr — Today

The team

Francesco D’Eramo

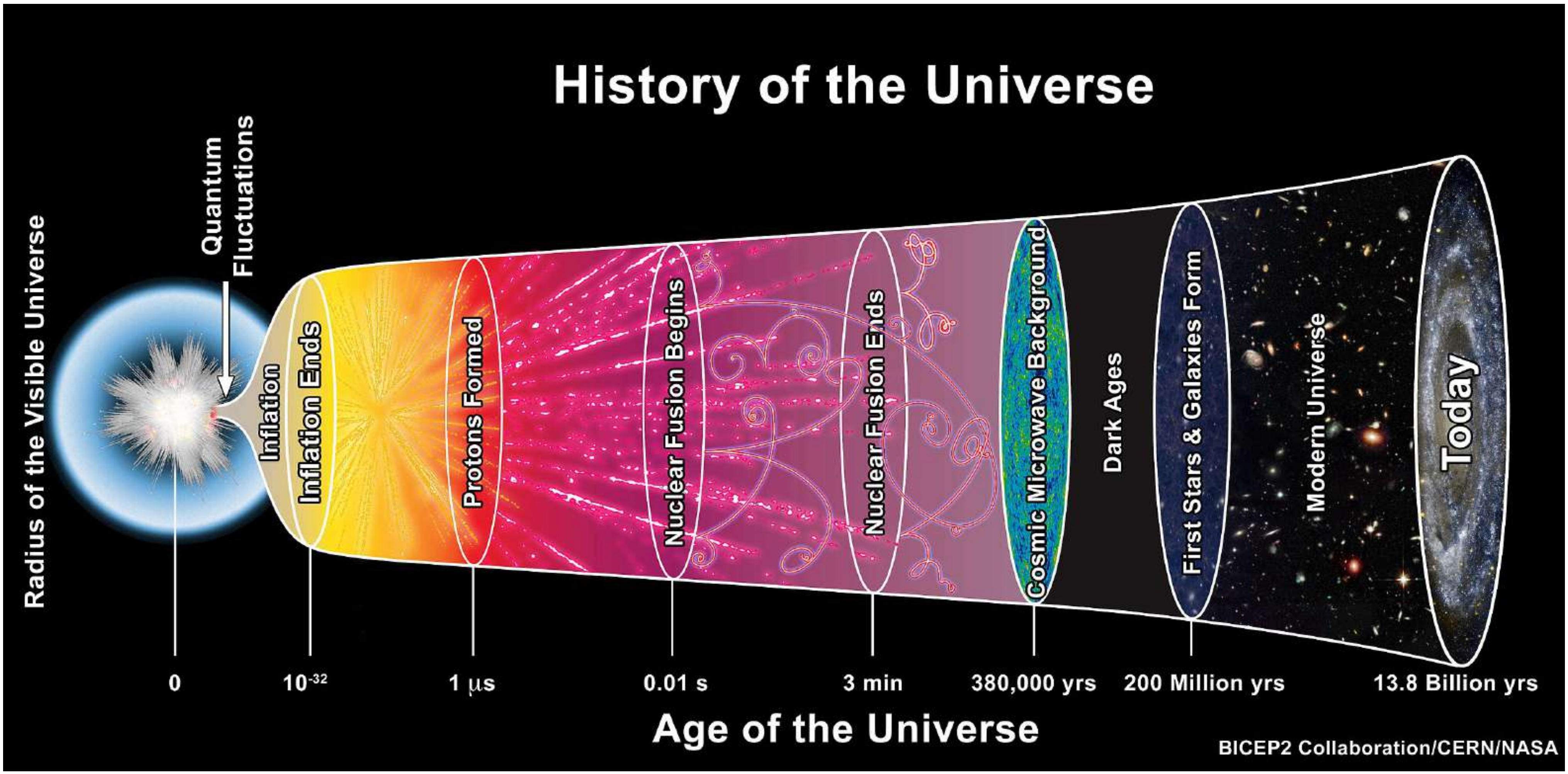




- **WHAT:** Particle physics identity of the Dark Universe
- **HOW:** Developing new theoretical tools to describe their microscopic properties *and* predict the experimental signals
- **WHY:** The Dark Universe accounts for 95% of the total energy budget, unveiling its composition is one of the most urgent open questions in physics of the fundamental interactions

Francesco D'Eramo

The Universe is a laboratory for particle physics where we can probe energy scales and densities not accessible via terrestrial experiments



Francesco D’Eramo

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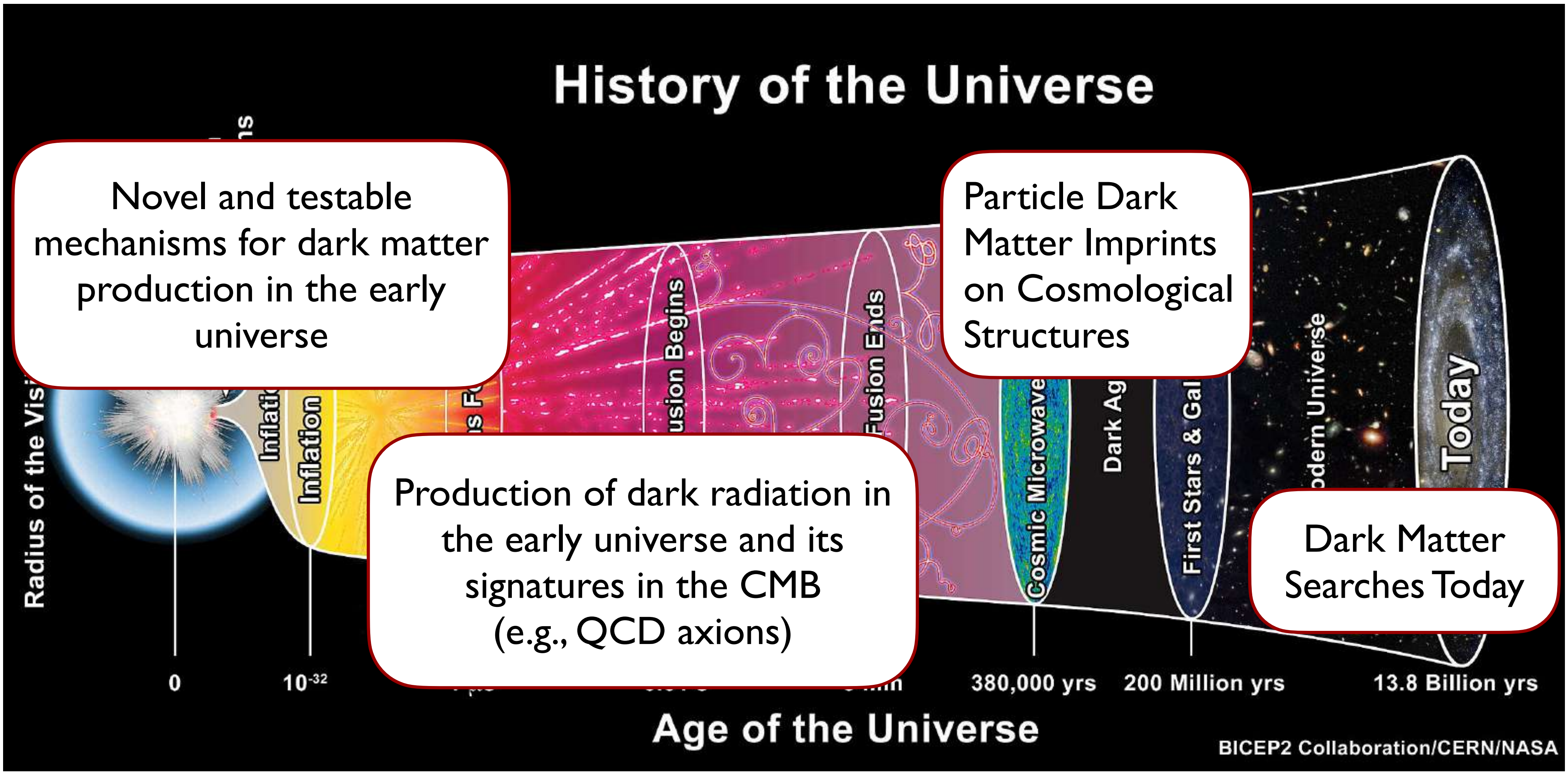


Francesco D'Eramo

Some Recent Work

PHYSICAL REVIEW LETTERS 128, 152001 (2022)

Thermal Axion Production at Low Temperatures: A Smooth Treatment of the QCD Phase Transition

Francesco D'Eramo,[*] Fazlollah Hajkarim,[†] and Seokhoon Yun[‡]
Dipartimento di Fisica e Astronomia, Università degli Studi di Padova, Via Marzolo 8, 35131 Padova, Italy and INFN, Sezione di Padova, Via Marzolo 8, 35131 Padova, Italy

(Received 2 September 2021; accepted 23 March 2022; published 13 April 2022)

JHEP
PUBLISHED FOR SISSA BY SPRINGER
RECEIVED: *June 2, 2023*
REVISED: *September 22, 2023*
ACCEPTED: *December 3, 2023*
PUBLISHED: *December 13, 2023*

Terrestrial detection of hidden vectors produced by solar nuclear reactions

Francesco D'Eramo,[a,b] Giuseppe Lucente,[c,d] Newton Nath[d] and Seokhoon Yun[a,b,e]

JHEP
PUBLISHED FOR SISSA BY SPRINGER
RECEIVED: *March 11, 2021*
REVISED: *April 27, 2021*
ACCEPTED: *May 5, 2021*
PUBLISHED: *May 25, 2021*

Displaced new physics at colliders and the early universe before its first second

Lorenzo Calibbi,[a] Francesco D'Eramo,[b,c] Sam Junius,[d,e,f] Laura Lopez-Honorez[d,e] and Alberto Mariotti[e,f]

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Lower mass bounds on FIMP dark matter produced via freeze-in

Francesco D'Eramo[a,b] and Alessandro Lenoci[a,b,c]

Some Recent Students

- Federico Pavone (exp. 2024, after Ph.D. at Stanford)
- Federico Cima (2022, after Ph.D. at Caltech)
- Alessandro Lenoci (2020, after Ph.D. at DESY)
- Emanuele Copello (2019, after Ph.D. at TUM)
- Giovanni Pierobon (2019, after Ph.D. at New South Wales)
- Alessandro Granelli (2018, after Ph.D. at SISSA)

Antonio Masiero

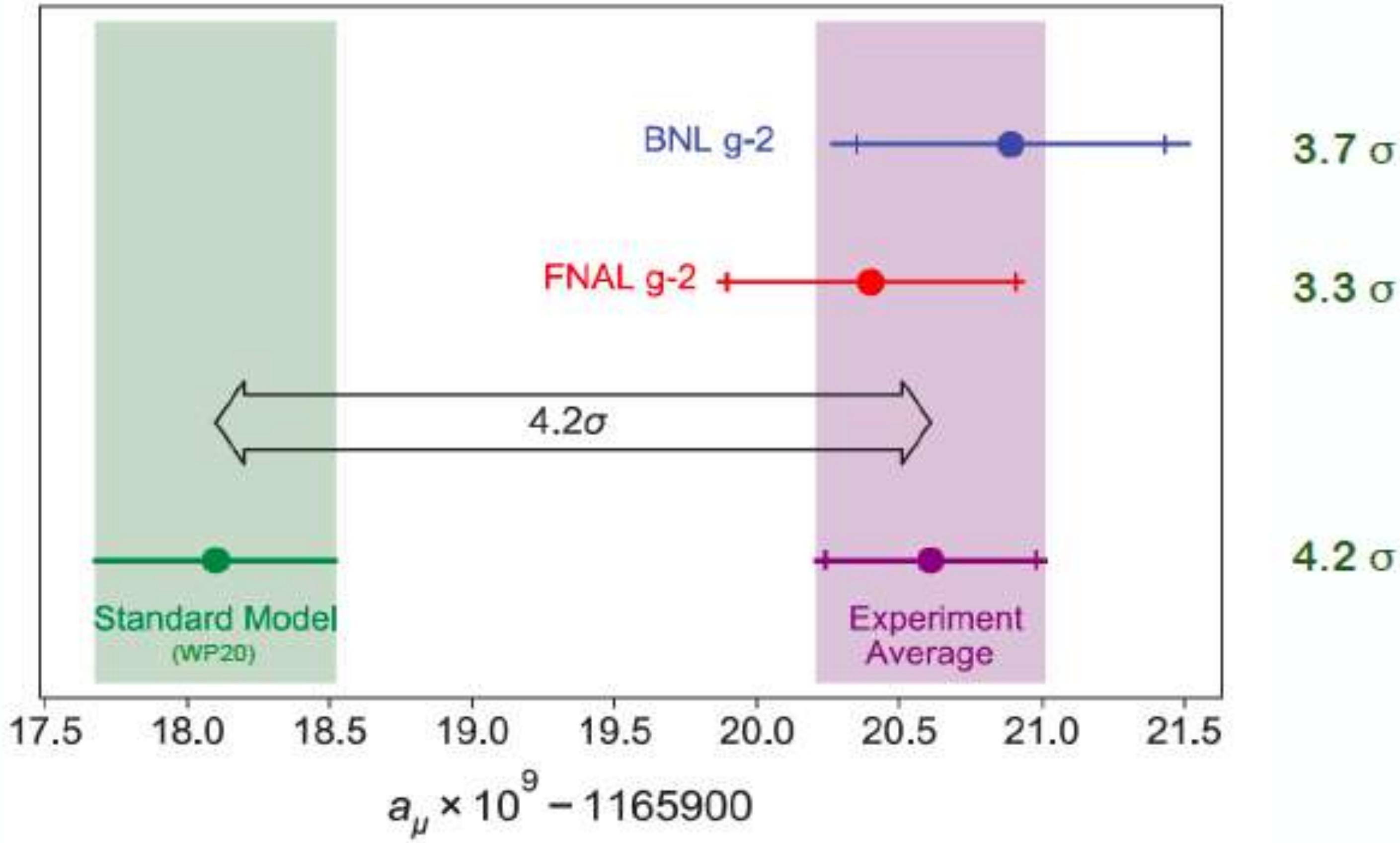
- **AstroParticle Physics** → in particular, DM candidates, cosmic matter-antimatter aymmetry, neutrino masses and neutrino cosmology

- Connections between the above astroparticle topics and BSM physics in **HIGH-ENERGY collider physics** & **LOW-ENERGY (high) precision physics**

- **Low-energy physics: the HIGH-INTENSITY frontier (Flavor physics, Lepton Flavor violation (ex. μ → e + γ), Lepton Flavor universality, etc.) & Low-energy high precision physics Electric and Magnetic Dipole moments, ex. the muon magnetic moment**

- **From possible (tiny) discrepancies between SM expectations and observations → theoretical BSM physics models with NEW particles/interactions → their role in the above astroparticle puzzles**

Muon g-2: FNAL confirms BNL



$a_\mu^{EXP} = (116592089 \pm 63) \times 10^{-11}$ [0.54ppm] BNL E821

$a_\mu^{EXP} = (116592040 \pm 54) \times 10^{-11}$ [0.46ppm] FNAL E989 Run 1

$a_\mu^{EXP} = (116592061 \pm 41) \times 10^{-11}$ [0.35ppm] WA

- **FNAL aims at 16 x 10^{-11}. First 4 runs completed, 5th in progress.**
- **Muon g-2 proposal at J-PARC: Phase-1 with ~ BNL precision.**

NEW PHYSICS for the muon g-2: at which scale?

$$\Delta a_\mu \equiv a_\mu^{\rm NP} \approx (a_\mu^{\rm SM})_{weak} \approx \frac{m_\mu^2}{16\pi^2 v^2} \approx 2 \times 10^{-9}$$

- A weakly interacting NP at $\Lambda \approx v$ can naturally explain $\Delta a_\mu \approx 2 \times 10^{-9}$
- $\Lambda \approx v$ favoured by the *hierarchy problem* and by a WIMP DM candidate.

On the other hand, HE experiments (LEP, Tevatron, LHC) have NOT provided any clue for the presence of new (charged) particles at the ELW. scale

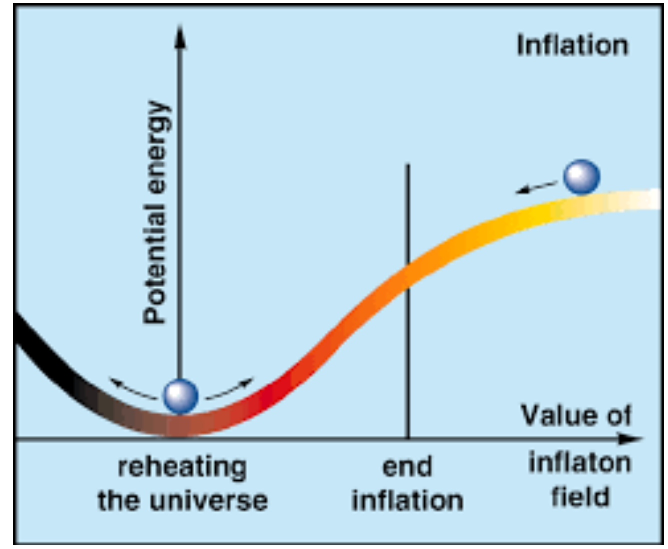
- NP is very light ($\Lambda \lesssim 1$ GeV) and feebly coupled to SM particles.
- NP is very heavy ($\Lambda \gg v$) and strongly coupled to SM particles.

P. Paradisi, La Thuile 202

The case of AXION-LIKE PARTICLES (ALPs)

Marco Peloso: inflation

Accelerated expansion, explains homogeneity, isotropy, flatness, and primordial perturbations with observed properties. Driven by field ϕ (inflaton) with flat potential



ϕ–interactions

Non-G $\delta\rho$

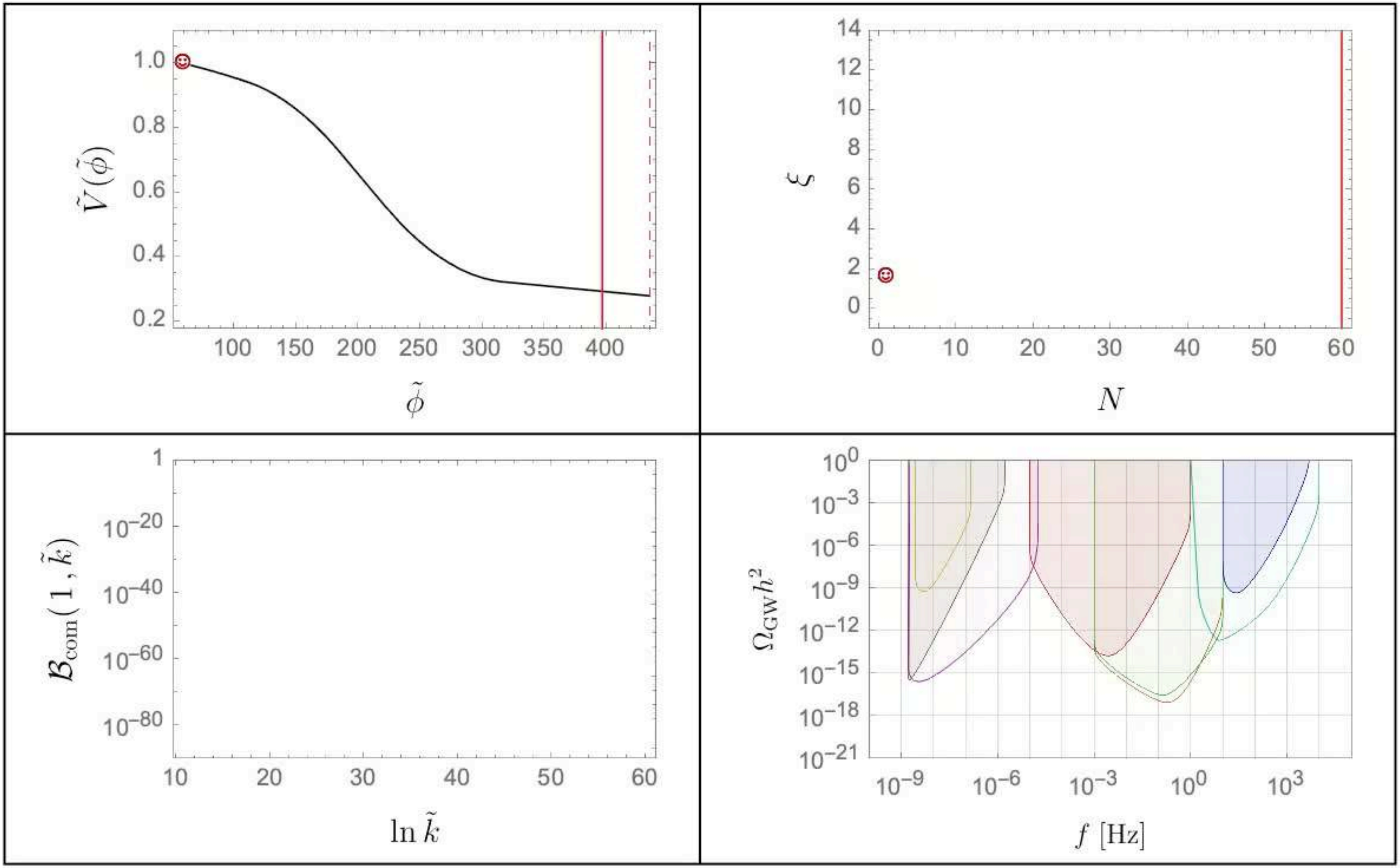
PBH

GW

Baryon asymmetry

Inflation in steep potentials

Garcia-Bellido, Papageorgiou, MP, Sorbo '23



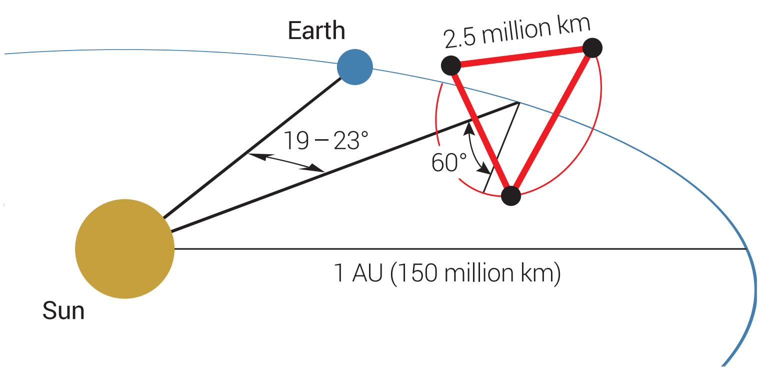
Marco Peloso: GW

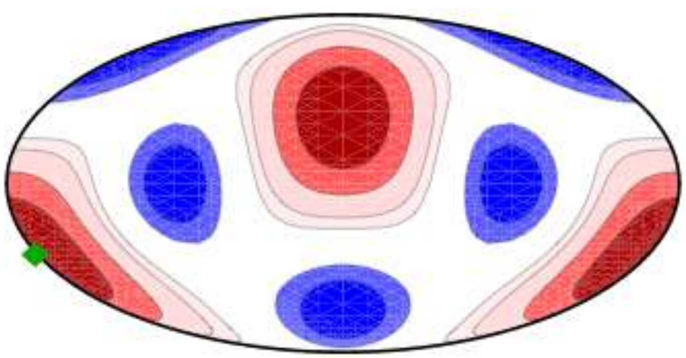
- Detected from ground (LIGO, Virgo, KAGRA) and from Pulsar Timing Arrays

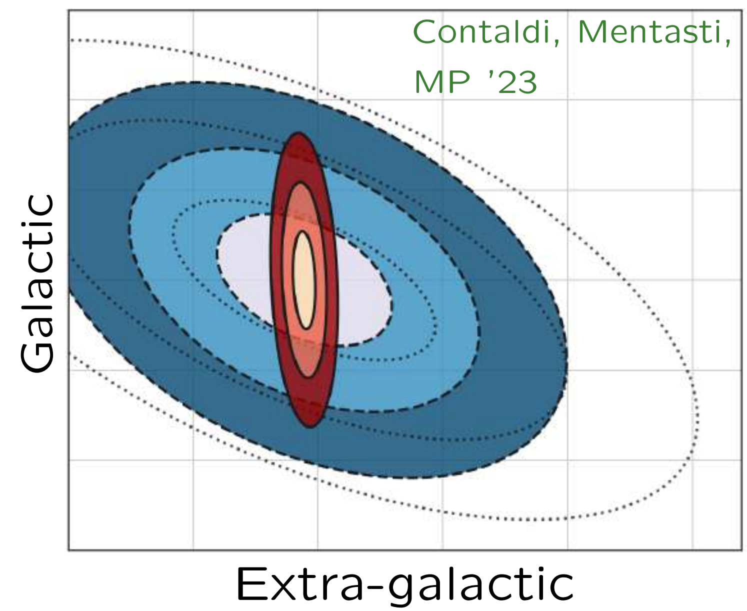
  Approved space mission LISA, mid 2030

- Co-chiar of LISA Cosmology Working Group (400+ members)

  Recently, extended activity in anisotropy of stochastic GW backround







- In Padua, 8 master + 1 bachelor students (about 2/year)

Edoardo Vitagliano

Known unknowns

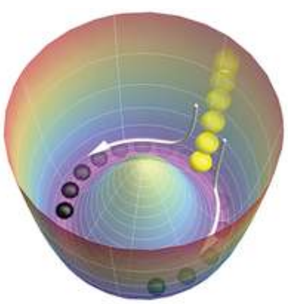
?

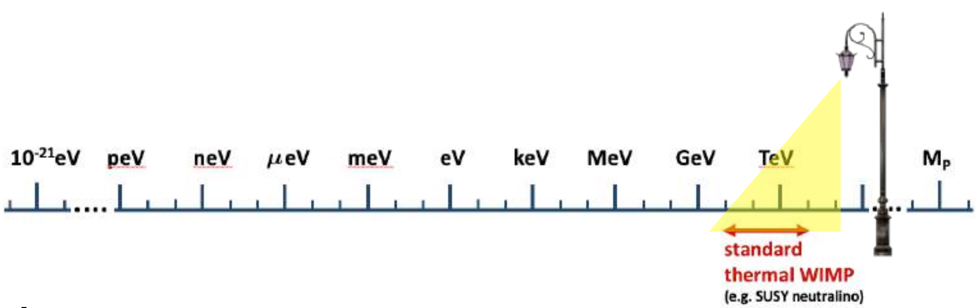
- Nature of dark matter
- Neutrino masses
- Matter-antimatter asymmetry
- Many others (inflation, nature of dark energy, Hubble tension, $g_\mu - 2$...)

Think outside of the box

!

- Answer more than one question
- Connect the smallest and the largest scales
- Look for answers in different places (theory parameter space) and ways





Feebly interacting particles

Primordial black holes

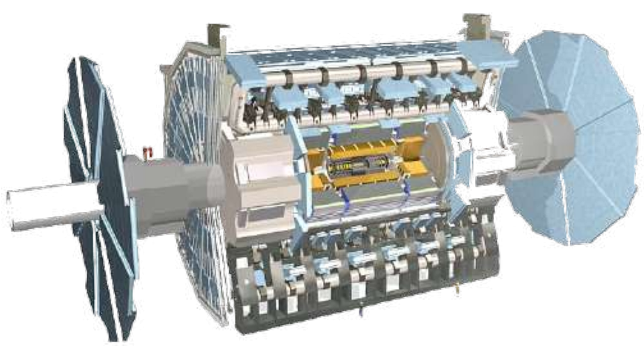
Edoardo Vitagliano

Specialty of the house:

Feebly interacting particles (FIPs—axion, majoron...)

Paradigm shift

BEFORE



In collider physics: new physics is invisible because new particles are very heavy and you need large energies to produce them

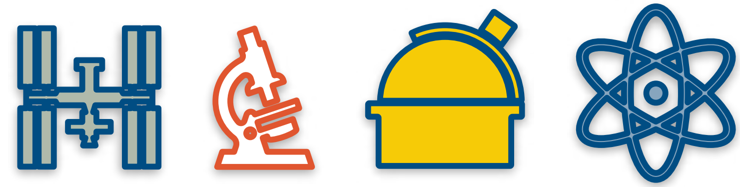
NOW

Feebly interacting particles: difficult to detect because their coupling is small, no need for large energies

Edoardo Vitagliano

Known unknowns...

...combining astrophysics, particle physics, cosmology, condensed matter...



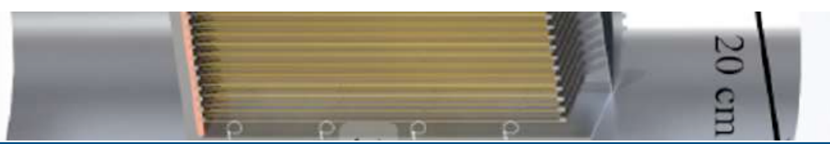
...we can find answers!

Inventing new detectors

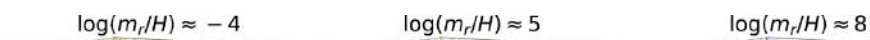
Featured in Physics | Editors' Suggestion | Open Access

Tunable Axion Plasma Haloscopes

Matthew Lawson, Alexander J. Millar, Matteo Pancaldi, Edoardo Vitagliano, and Frank Wilczek
Phys. Rev. Lett. **123**, 141802 – Published 1 October 2019



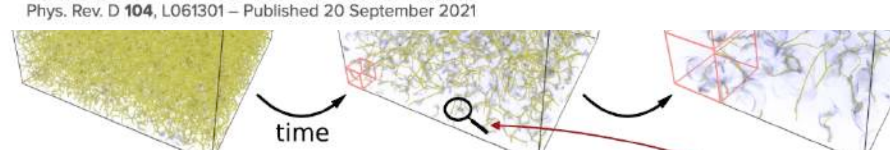
Topological defects and gravitational waves



Letter | Open Access

Gravitational waves from axionlike particle cosmic string-wall networks

Graciela B. Gelmini, Anna Simpson, and Edoardo Vitagliano
Phys. Rev. D **104**, L061301 – Published 20 September 2021



Looking for astronomical signals

Exploring Primordial Black Holes from the Multiverse with Optical Telescopes

Alexander Kusenko, Misao Sasaki, Sunao Sugiyama, Masahiro Takada, Volodymyr Takhistov, and Edoardo Vitagliano
Phys. Rev. Lett. **125**, 181304 – Published 30 October 2020

Astrophysics as a laboratory for particle physics

Low-Energy Supernovae Severely Constrain Radiative Particle Decays

Andrea Caputo, Hans-Thomas Janka, Georg Raffelt, and Edoardo Vitagliano
Phys. Rev. Lett. **128**, 221103 – Published 3 June 2022

Edoardo Vitagliano