Workshop di Sezione sulla Strategia Europea per la Fisica delle Particelle Elementari
Bari, 21/11/2024

THE SEARCH FOR FEEBLY INTERACTING PARTICLES (FIPs) AT THE INTENSITY FRONTIER

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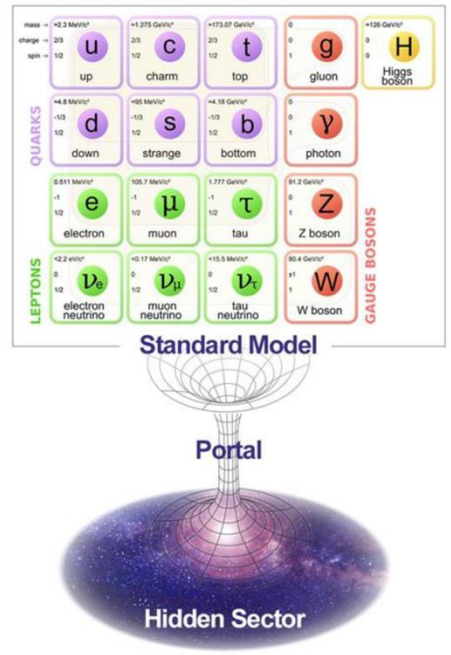


«Measure what can be measured, and make measurable what cannot be»
(Galileo Galilei)

OPEN QUESTIONS

- What is dark matter?
- What dynamics is responsible for neutrino masses?
- How is the matter-antimatter asymmetry generated?
- What physics underlies the Higgs sector and sets the weak scale?
- Why is CP conserved by the strong interactions?

These and other questions strongly motivate explorations of physics beyond the SM.

PREAMBLE

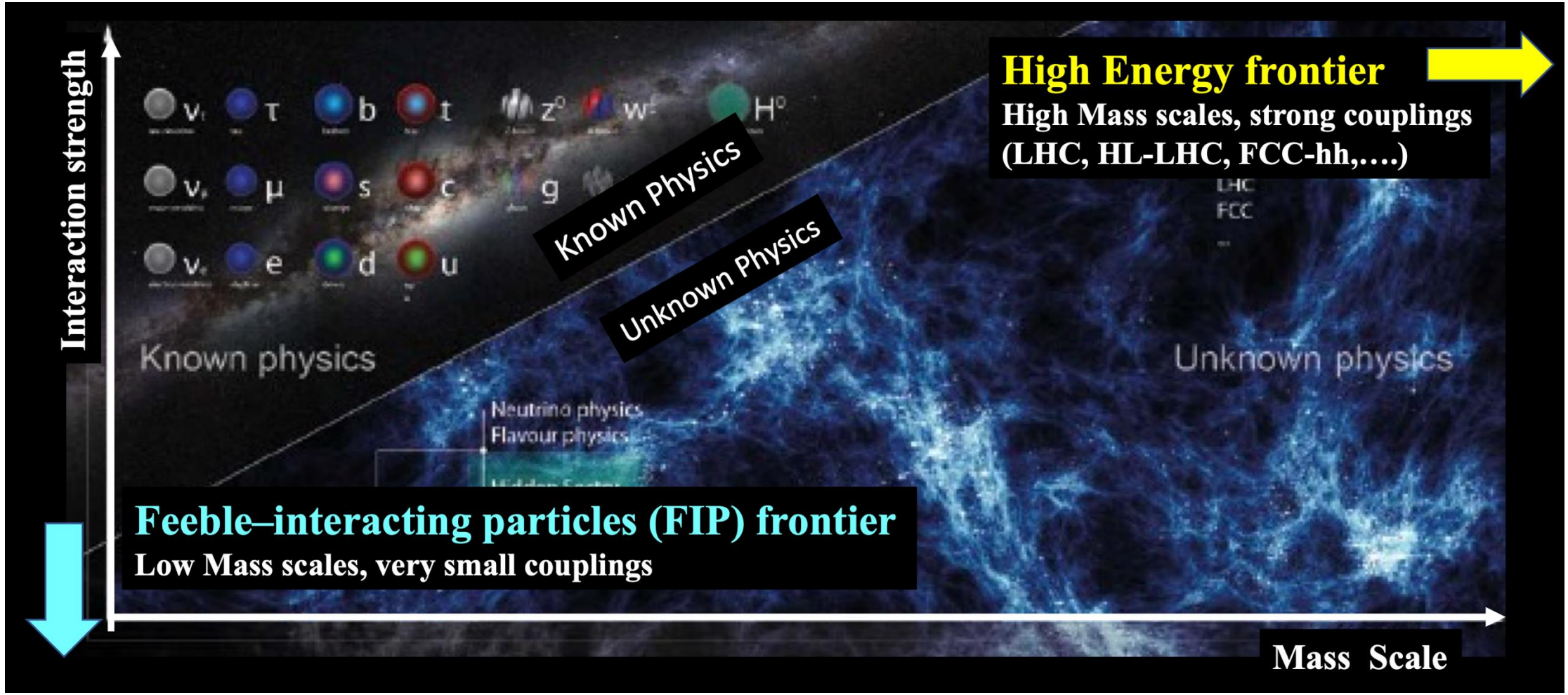
CERN-ESU-004
10 January 2020

Physics Briefing Book

Input for the European Strategy for Particle Physics Update 2020

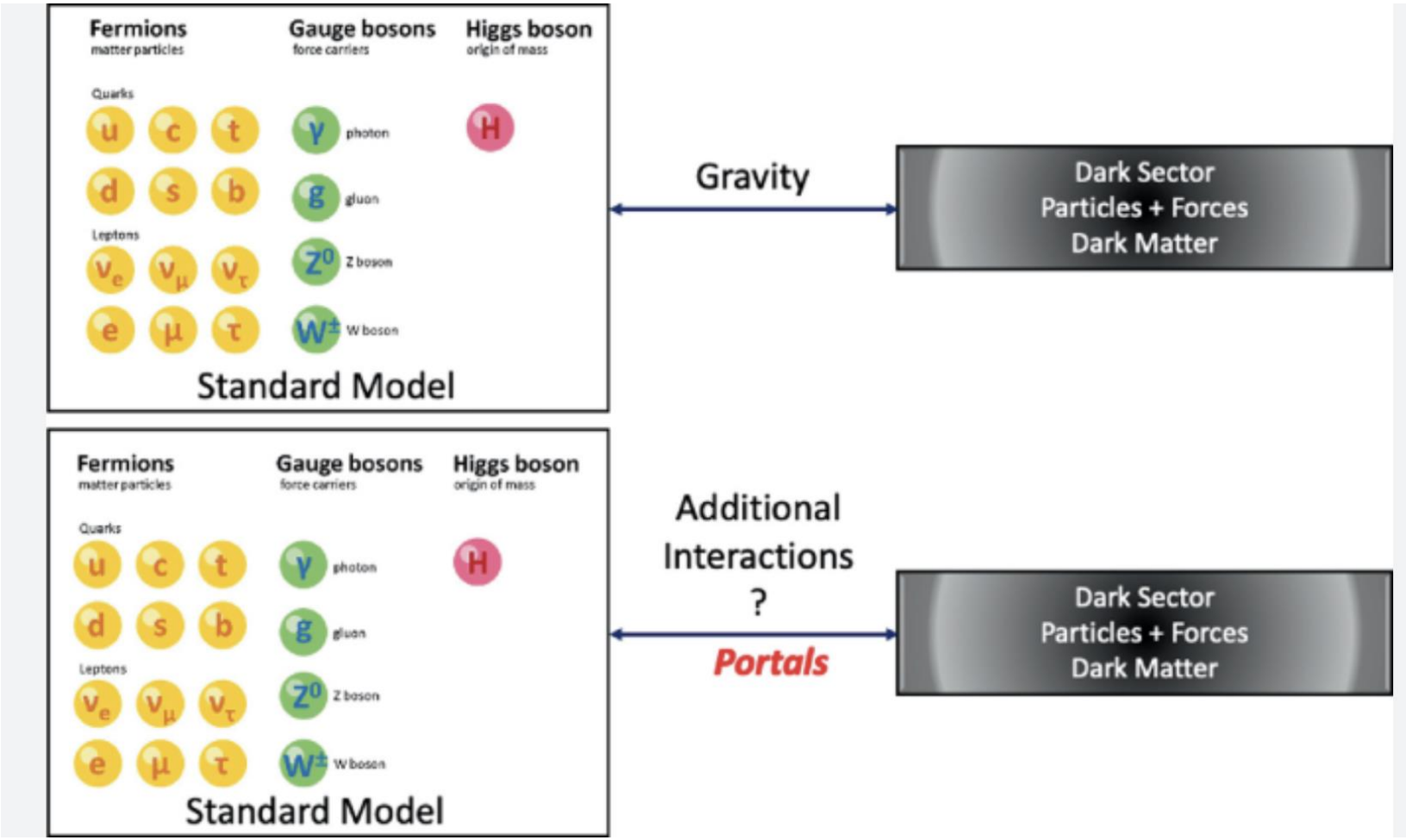
4. To what extent can current or future accelerators probe feebly-interacting sectors?

The absence, so far, of unambiguous signals of new physics from direct searches at the LHC, indirect searches in flavour physics and direct DM detection experiments invigorates the need for broadening the experimental effort in the quest for new physics and in exploring ranges of interaction strengths and masses different from those already covered by existing or planned projects. *While exploration of the high-mass frontier remains an essential target, other research directions have valid theoretical motivations and deserve equal attention.* Feebly-interacting particles (see Sect. 8.6) represent an alternative paradigm with respect to the traditional BSM physics explored at the LHC. The full investigation of this paradigm over a large range of couplings and masses requires a great variety of experimental facilities. In this context, the physics reach of experiments at future colliders is complemented by beam-dump facilities which typically cover the range of low masses and extremely feeble couplings.


Interaction strength
High Energy frontier
High Mass scales, strong couplings
(LHC, HL-LHC, FCC-hh,….)
Known Physics
Unknown Physics
Known physics
Unknown physics
Neutrino physics
Flavour physics
LHC
FCC
Feeble–interacting particles (FIP) frontier
Low Mass scales, very small couplings
Mass Scale

THE PORTAL TO DARK SECTOR

There may be a dark sector (or hidden sector, etc.) containing new SM gauge singlet states. The dark sector states may have masses well below the weak scale and communicate weakly with the visible sector through a portal interaction linking gauge invariant SM operators to a mediator.



HOW TO GET FIPs IN THE PORTAL APPROACH?

Expand the SM with the minimal set of operators of lowest dimension gauge-invariant and renormalizable. This guarantees that the theoretical structure of the SM is preserved and any NP is just a simple (natural?) extension of what we already know.

Portal	Coupling
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$
Axion, a	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\delta_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
Sterile Neutrino, N	$y_N L H N$

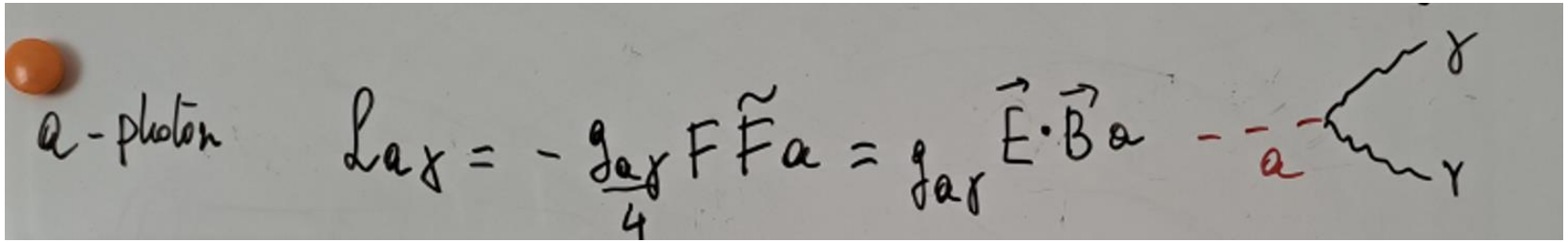
The full set of allowed renormalizable interactions for dark sector with SM, consistent with SM Gauge invariance (plus one notable generalization)

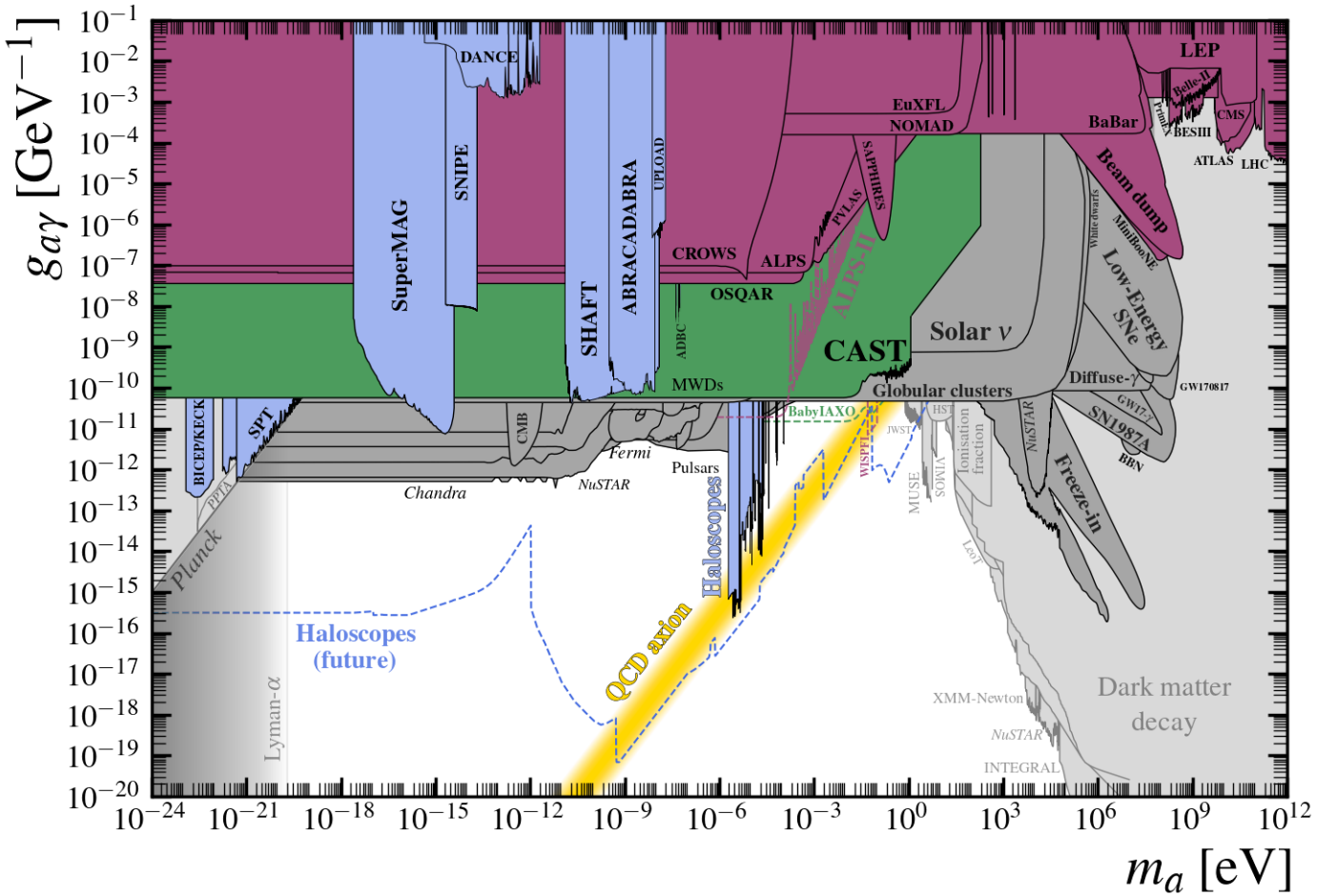
ESPP Recommendations

- *"4. Other essential scientific activities for particle physics:*
- *a) The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics.*
- *This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, dark sector candidates and feebly interacting particles.*
- *There are many options to address such physics topics including energy-frontier colliders, accelerator and non-accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy.*

https://cds.cern.ch/record/2721370/files/CERN-ESU-015 2020%20Update%20European%20Strategy.pdf

A PHYSICS CASE: AXIONS AND AXION-LIKE-PARTICLES (ALPs)



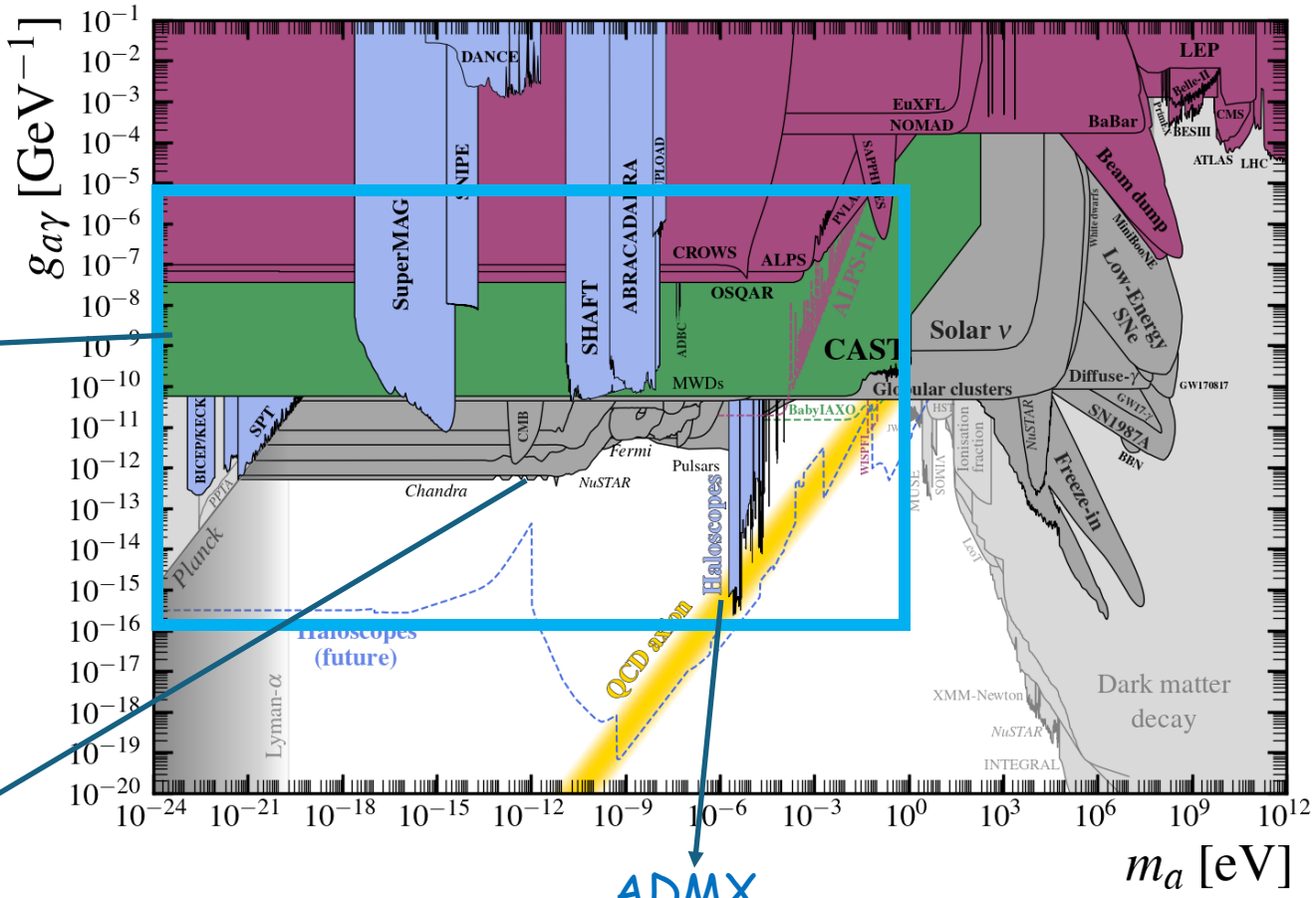


github.com/cajohare/AxionLimits

Sub-eV axions accessible at helioscopes (Sun) and haloscopes (DM)

CAST

Ultra-light axions from cosmic sources searched with X and gamma-ray telescopes

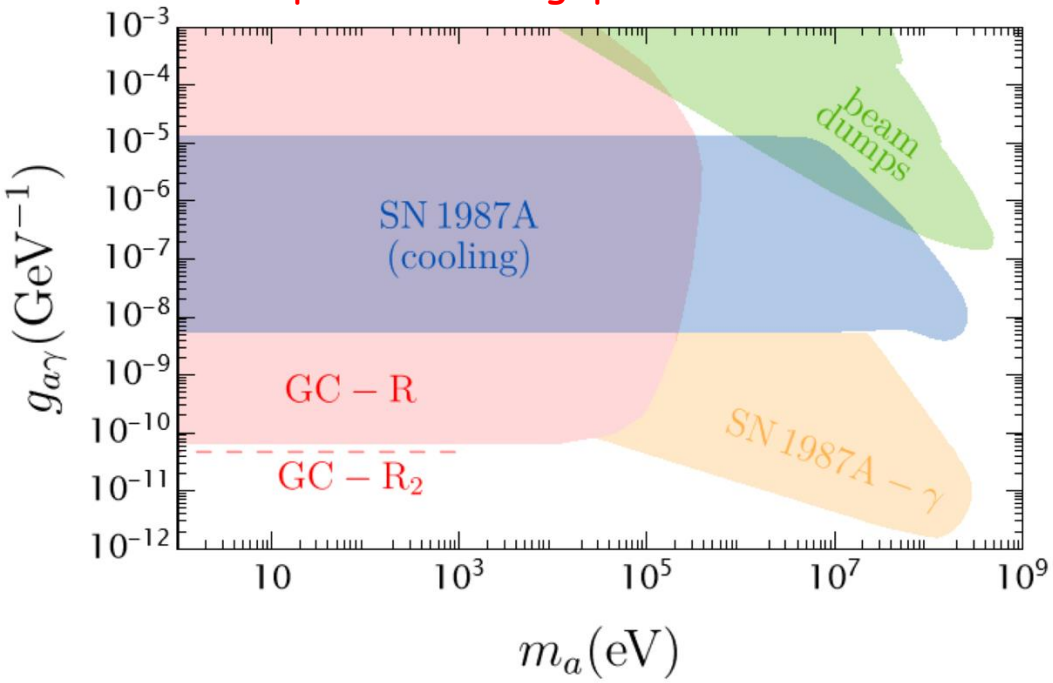


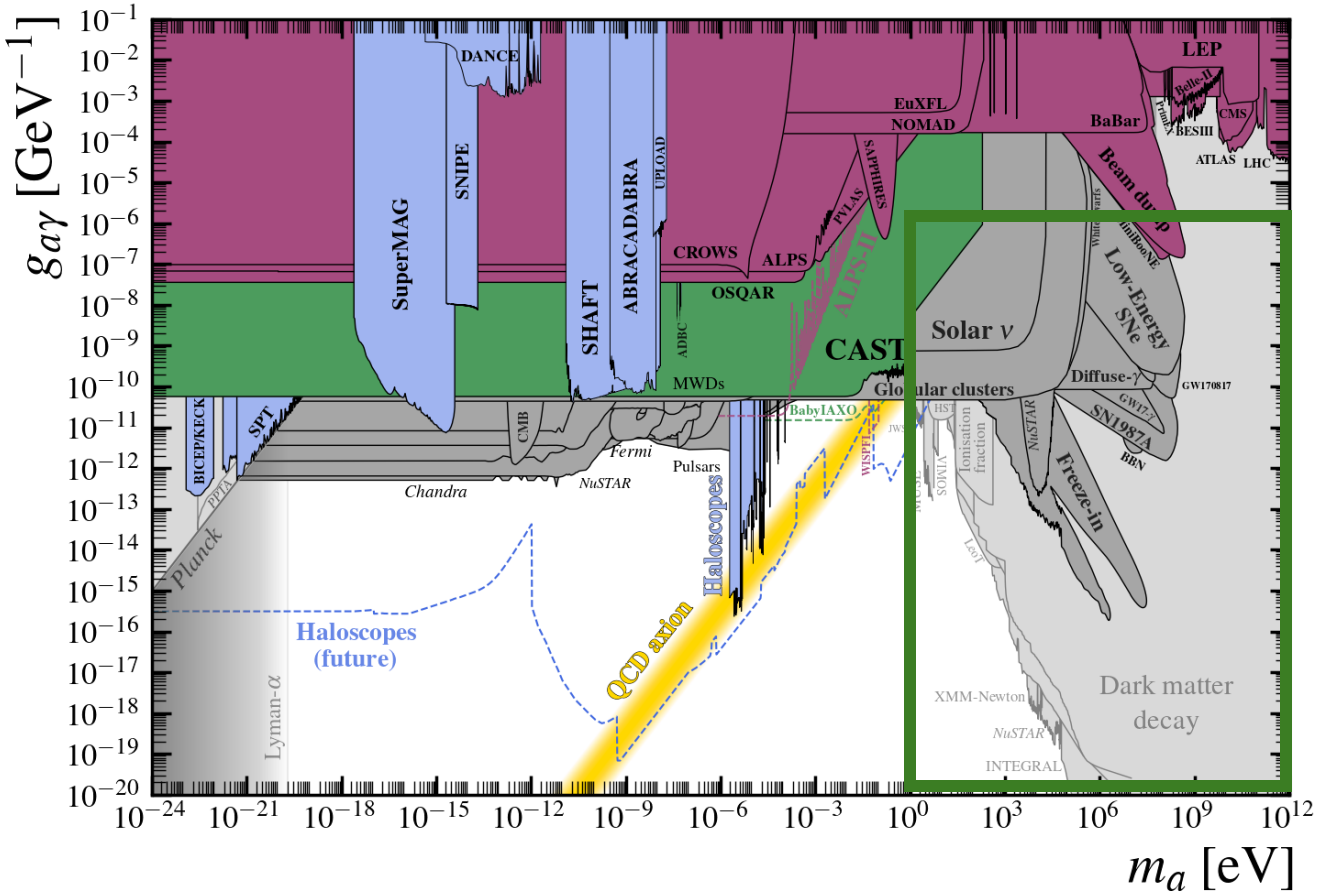
ADMX

Here axions can be DM

Astroparticle realm: BBN, CMB, X-rays, SN 1987A, Globular clusters, Solar lifetime, etc

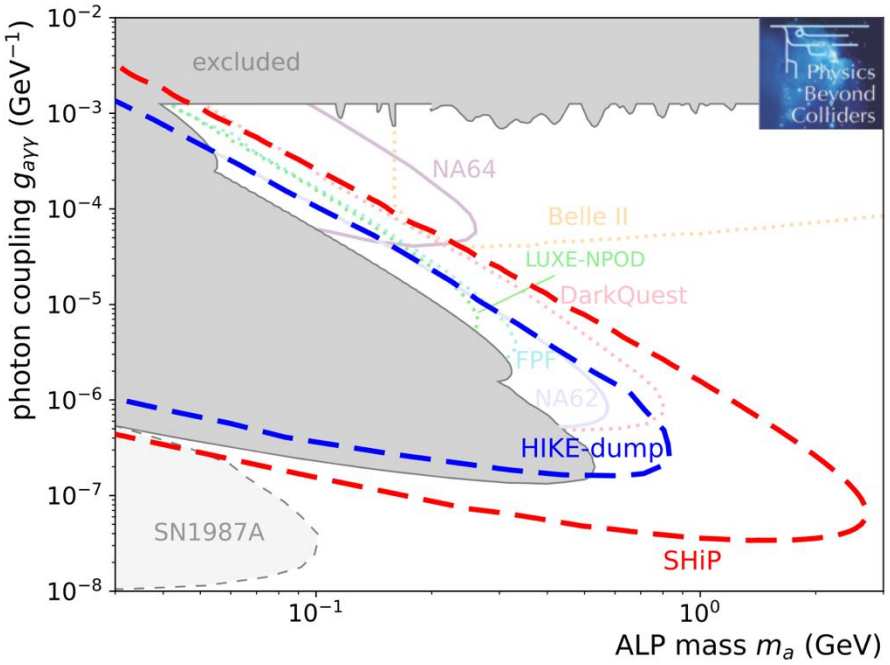
https://arxiv.org/pdf/2004.08399

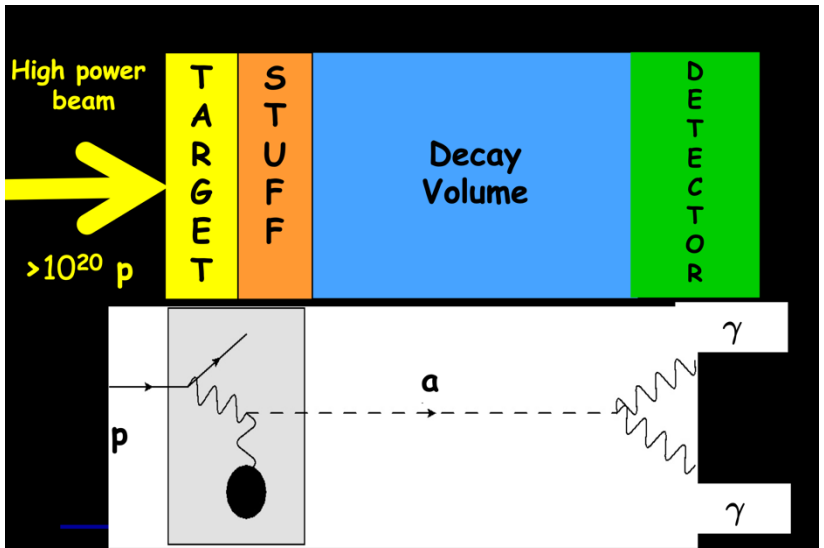


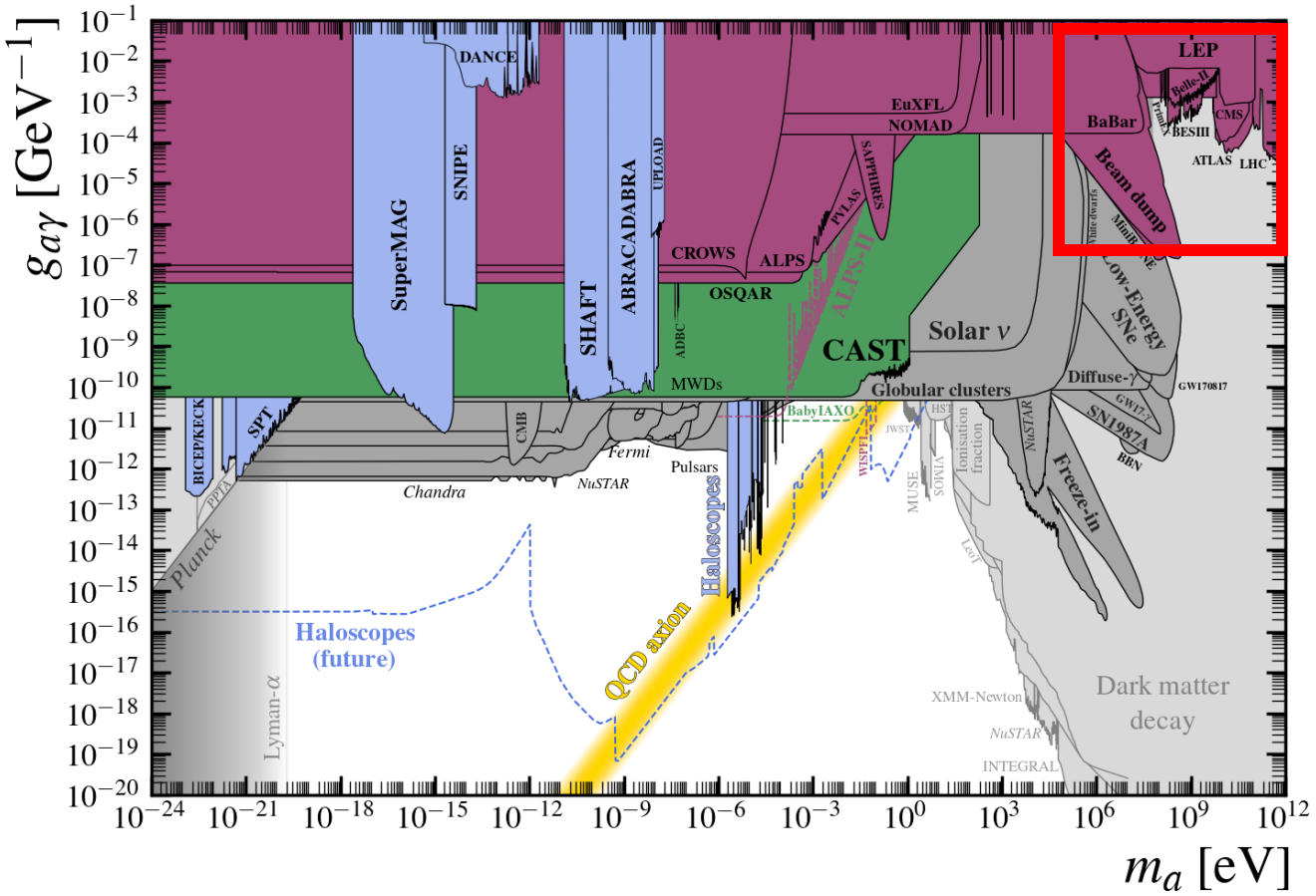


P. Carenza, M. Giannotti, J. Isern, A.Mirizzi and O. Straniero, «*Axion Astrophysics,*» [arXiv:2411.02492 [hep-ph]]. Prepated for Physics Report

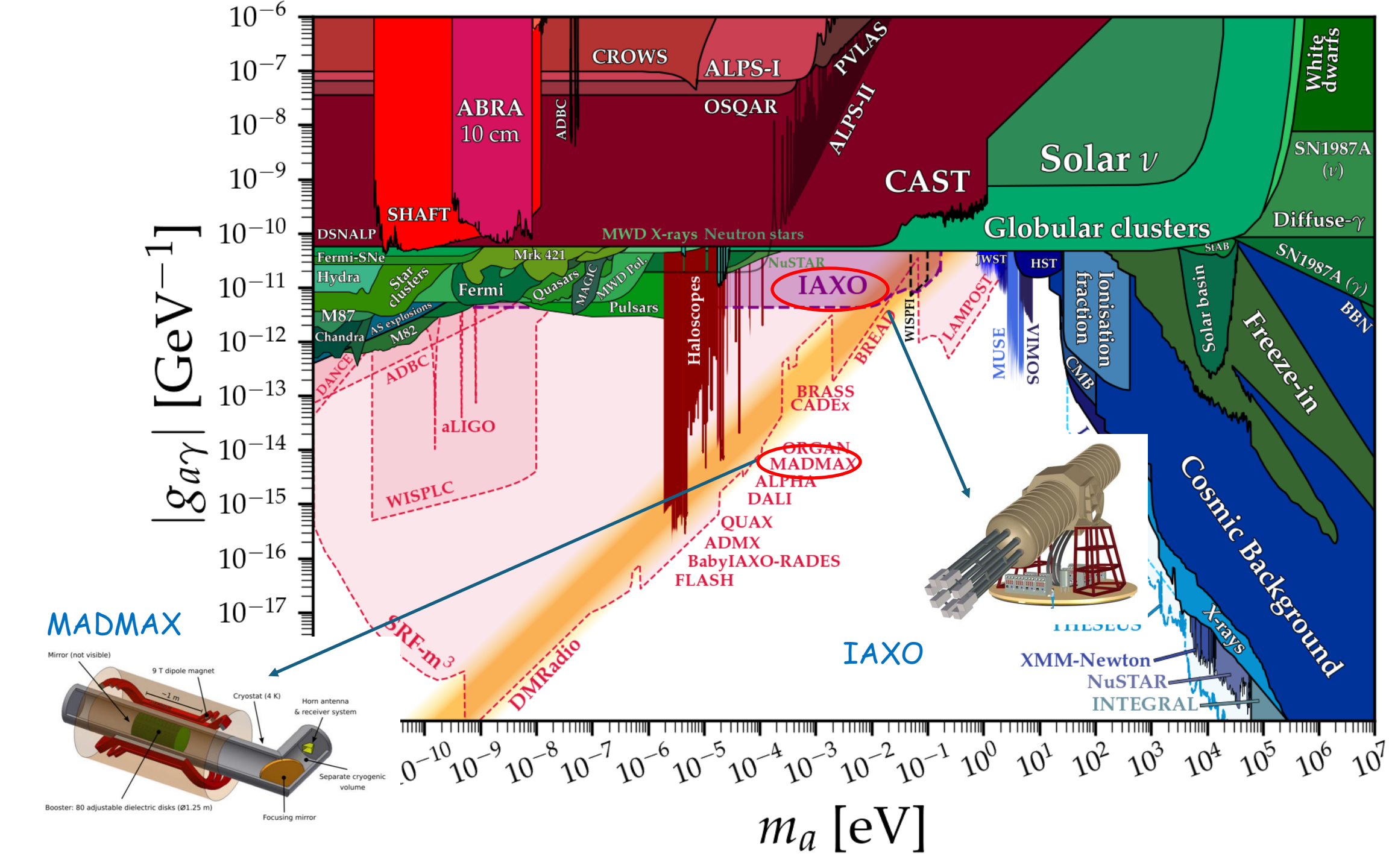
https://arxiv.org/pdf/2310.17726

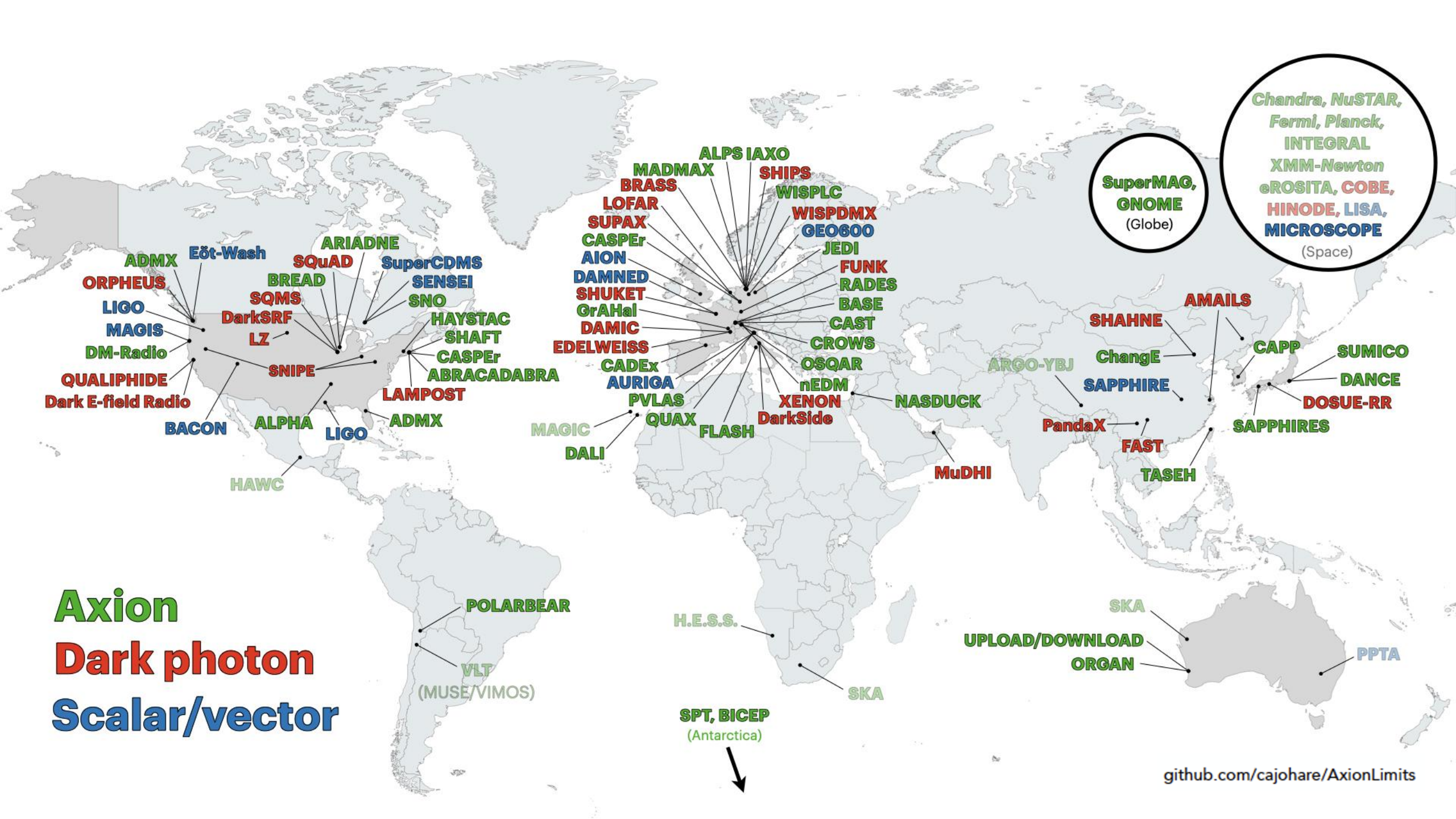






MeV-10 GeV range accessible at accelerator based experiments


$|g_{a\gamma}|$ [GeV^{-1}]
m_a [eV]
CROWS
ALPS-I
PVLAS
ALPS-II
OSQAR
ABRA
10 cm
ADBC
SHAFT
CAST
Solar ν
White dwarfs
SN1987A (ν)
Diffuse-γ
Globular clusters
DSNALP
MWD X-rays
Neutron stars
Fermi-SNe
Hydra
Star clusters
Mrk 421
Fermi
Quasars
MAGIC
MWD Pol.
Pulsars
NuSTAR
IAXO
M87
Chandra
AS explosions
M82
Haloscopes
WISPFI
LAMPOST
JWST
HST
MUSE
VIMOS
Ionisation fraction
CMB
StAB
Solar basin
SN1987A (γ)
BBN
Freeze-in
Cosmic Background
X-rays
DANCE
ADBC
aLIGO
WISPLC
BREAD
BRASS
CADEx
ORGAN
MADMAX
ALPHA
DALI
QUAX
ADMX
BabyIAXO-RADES
FLASH
SRF-m^3
DMRadio
THESEUS
XMM-Newton
NuSTAR
INTEGRAL
MADMAX
Mirror (not visible)
9 T dipole magnet
~1 m
Cryostat (4 K)
Horn antenna & receiver system
Separate cryogenic volume
Booster: 80 adjustable dielectric disks (Ø1.25 m)
Focusing mirror
IAXO


Chandra, NuSTAR, Fermi, Planck, INTEGRAL XMM-Newton eROSITA, COBE, HINODE, LISA, MICROSCOPE (Space)
SuperMAG, GNOME (Globe)
ALPS IAXO
MADMAX
SHIPS
BRASS
WISPLC
LOFAR
WISPDMX
SUPAX
GEO600
CASPEr
JEDI
AION
FUNK
DAMNED
RADES
SHUKET
BASE
GrAHal
CAST
DAMIC
CROWS
EDELWEISS
OSQAR
CADEx
nEDM
AURIGA
XENON
PVLAS
NASDUCK
QUAX
DarkSide
FLASH
MAGIC
DALI
MuDHI
ADMX
Eöt-Wash
ARIADNE
SQuAD
SuperCDMS
ORPHEUS
BREAD
SENSEI
LIGO
SQMS
SNO
MAGIS
DarkSRF
HAYSTAC
LZ
SHAFT
DM-Radio
CASPEr
SNIPE
ABRACADABRA
QUALIPHIDE
LAMPOST
Dark E-field Radio
BACON
ALPHA
LIGO
ADMX
HAWC
AMAILS
SHAHNE
CAPP
SUMICO
ChangE
ARGO-YBJ
DANCE
SAPPHIRE
DOSUE-RR
PandaX
SAPPHIRES
FAST
TASEH
POLARBEAR
H.E.S.S.
SKA
UPLOAD/DOWNLOAD
ORGAN
PPTA
VLT
(MUSE/VIMOS)
SPT, BICEP
(Antarctica)
Axion
Dark photon
Scalar/vector
github.com/cajohare/AxionLimits

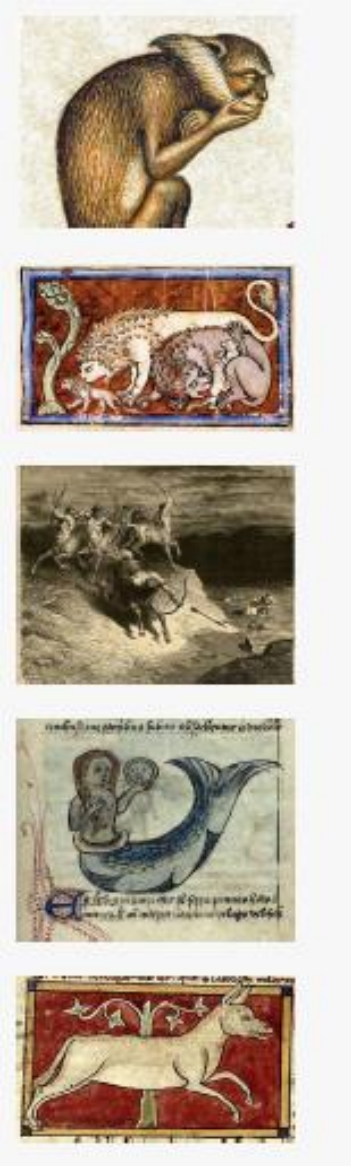
COST ACTION CA21106

COSMIC WISPers in the Dark Universe:

Theory, astrophysics and experiments

Funded by the European Union

cosmicwispers.eu

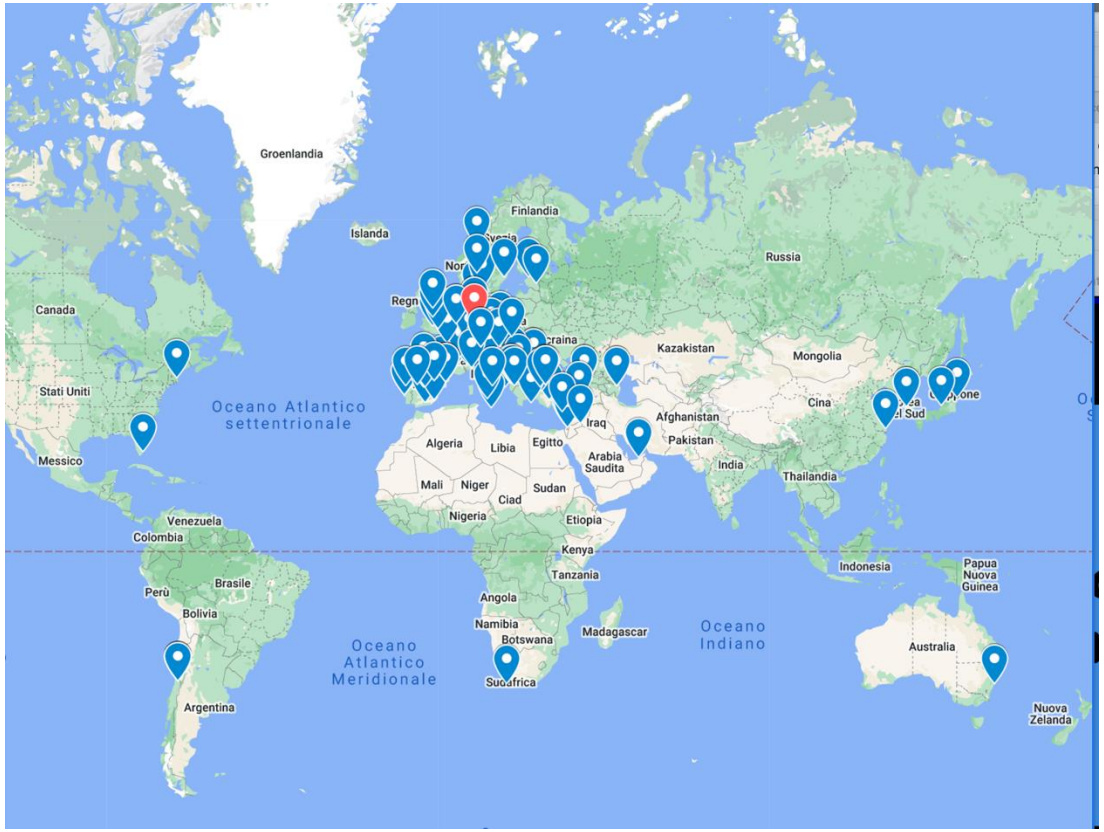


WISPs

WISPs are very Weakly Interacting Slim (m<GeV) Particles which emerge in several extensions of the Standard Model of Particle Physics.

CHALLENGE

The aim of this Action is an exhaustive study of these WISPs, notably axions, axion-like particles (ALPs) and dark photons, ranging from their theoretical underpinning, over their indirect observational consequences in astrophysics, to their search at colliders and beam-dump and their direct detection in laboratory experiments.



~ 400 participants from all over the world

CONCLUSIONS

- FIP physics is a field in full expansion, which has developed from a niche activity to a world-wide effort with significant competition.

- Planned experiments will allow to explore a significant part of parameter space in 10-20 years

- The international community needs support by integrating FIP searches in the future European strategy on particle physics

THE NEXT NEW BIG DISCOVERY COULD COME FROM HERE!