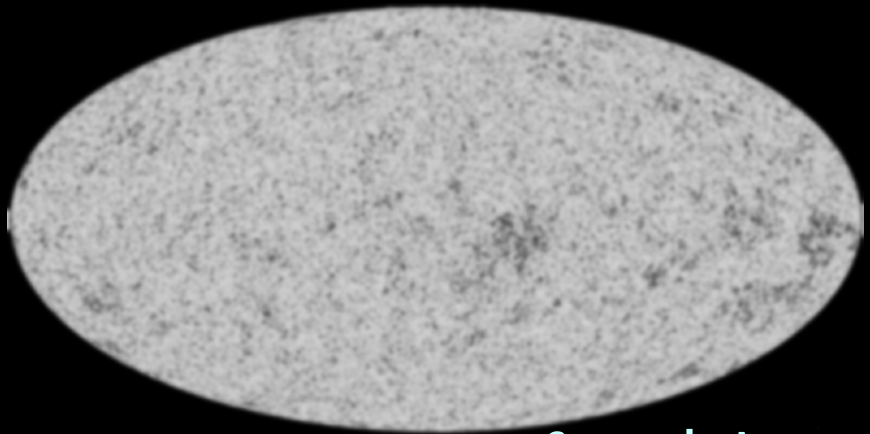
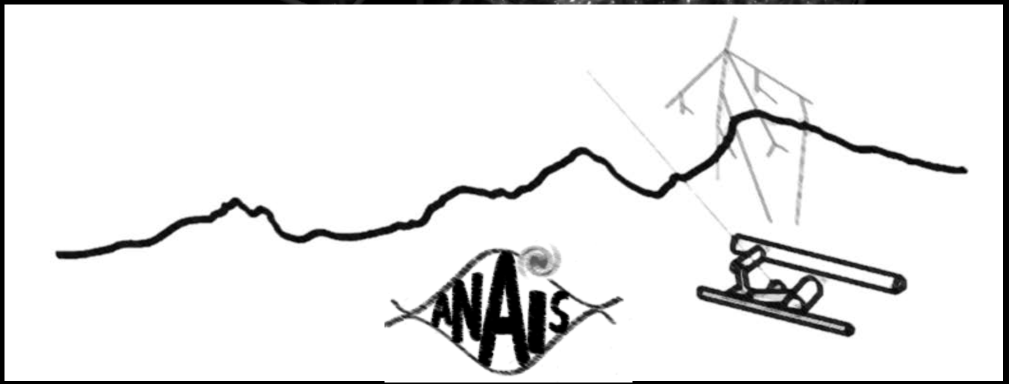


Particle Dark Matter

M.L. Sarsa
Centro de Astropartículas y Física de Altas Energías, UNIVERSIDAD DE ZARAGOZA



MultiDark
Multimessenger Approach for Dark Matter Detection

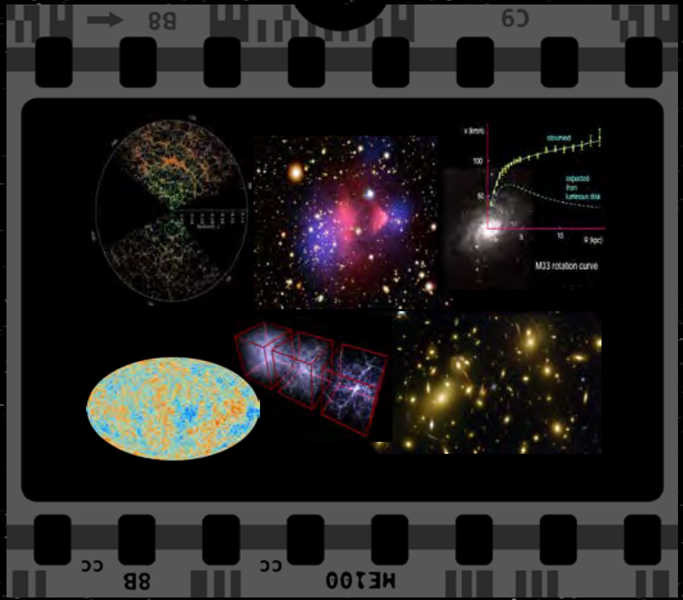
Sinergias SEA

THE NATURE OF DARK MATTER:
Where are we and where are we going?

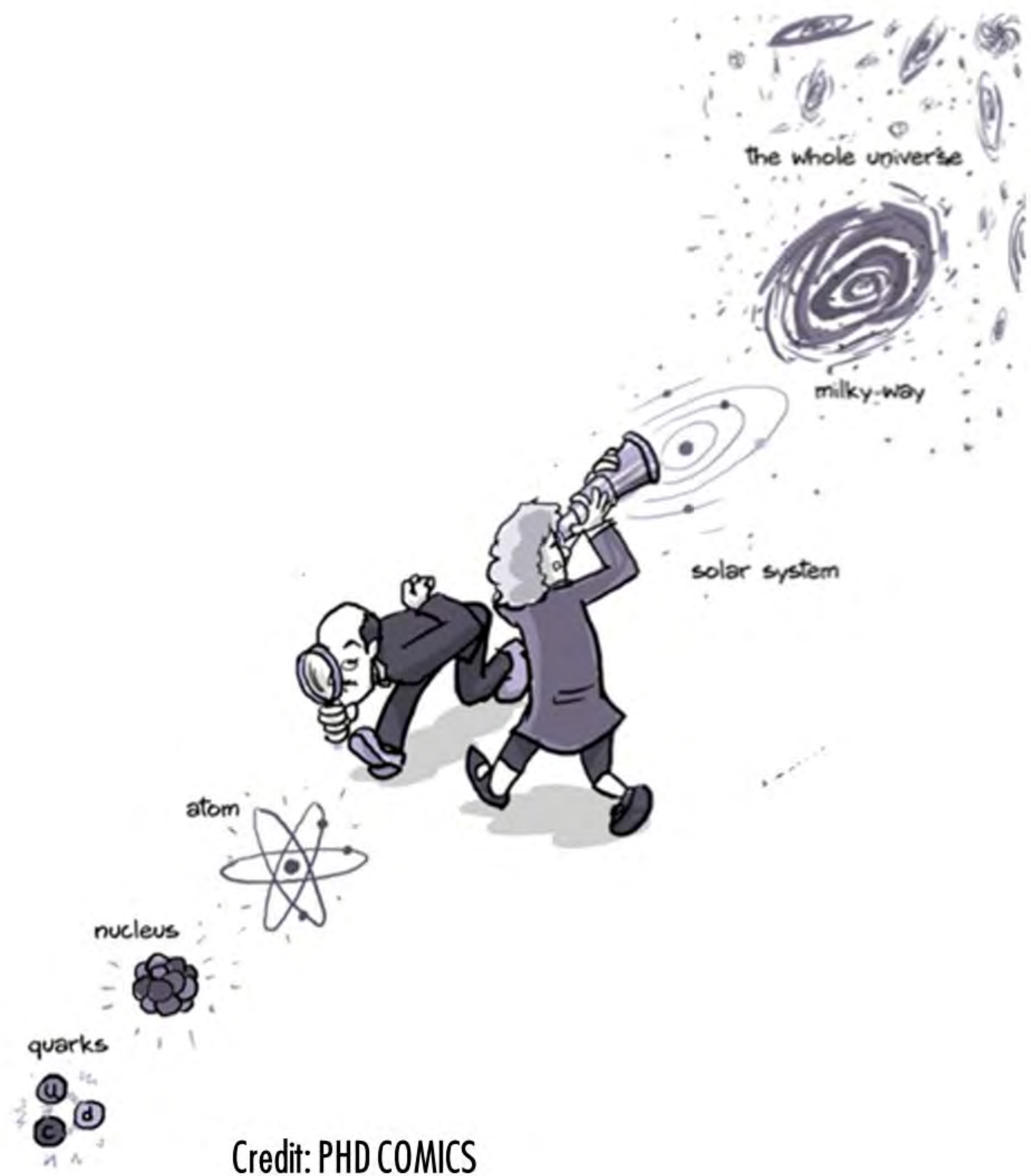
LSC
Laboratorio Subterráneo de Canfranc

CAPA
Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza

OUTLINE



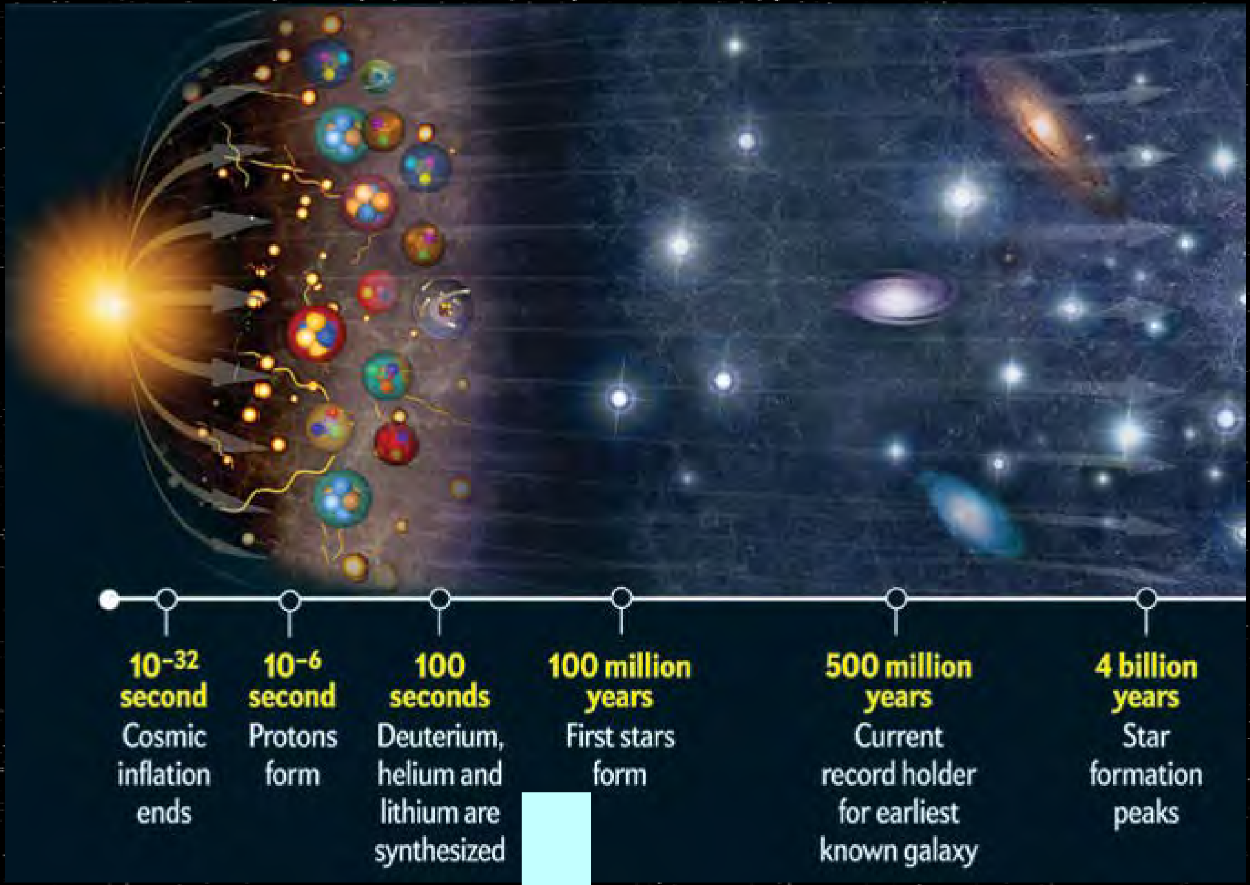
Evidences on DARK MATTER come from astrophysics and cosmology

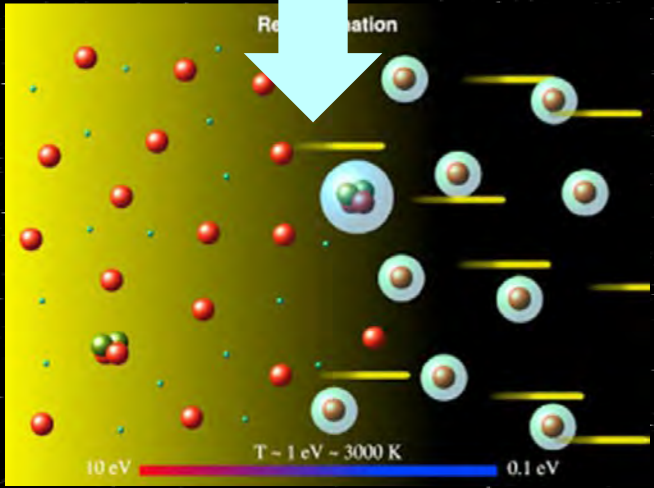


Credit: PHD COMICS

The early Universe

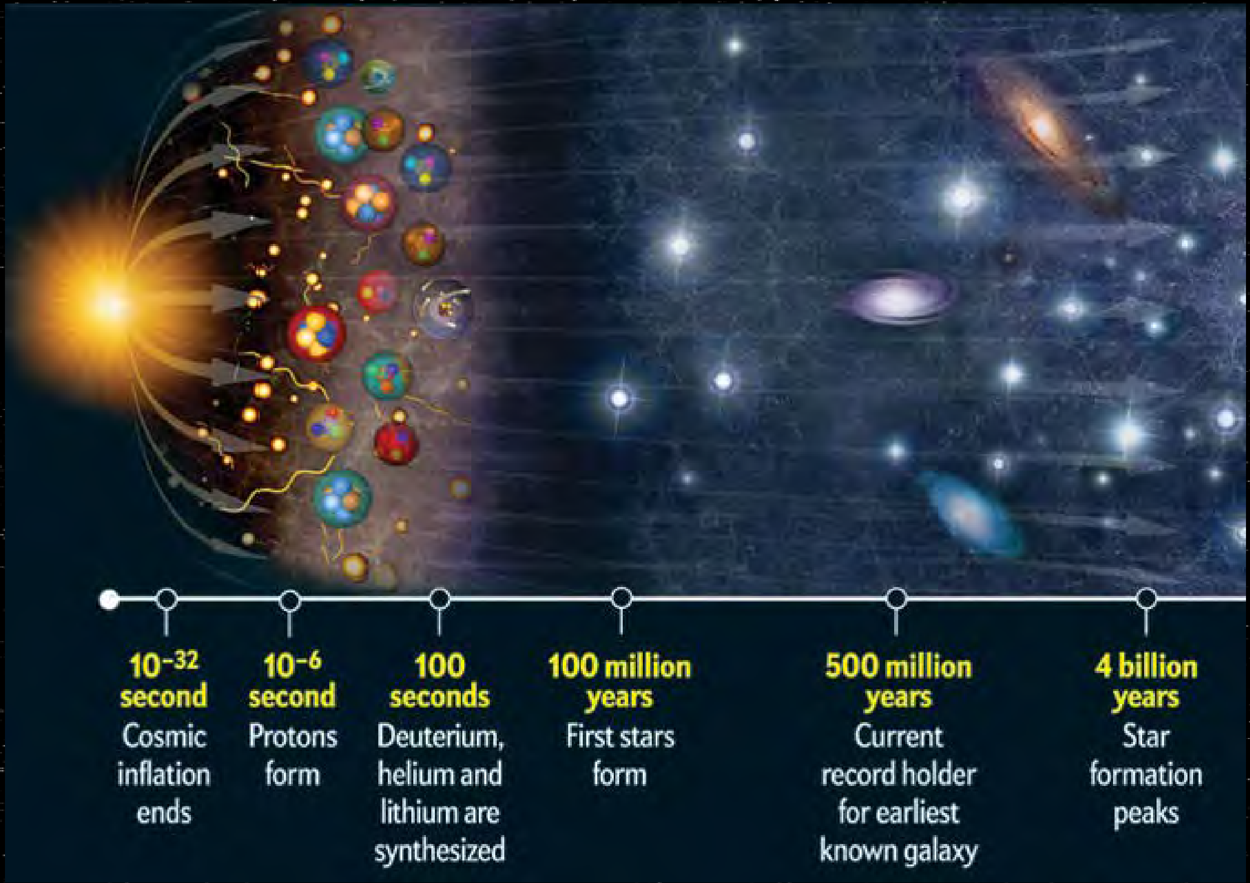
Nuclear and Particle Physics rules

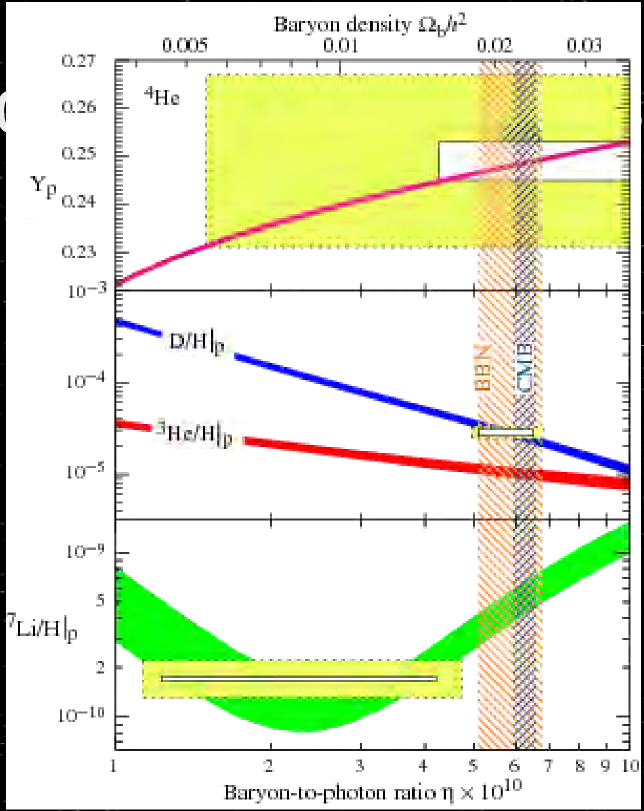


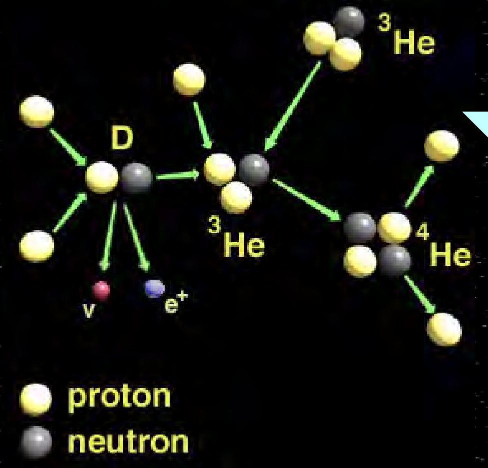


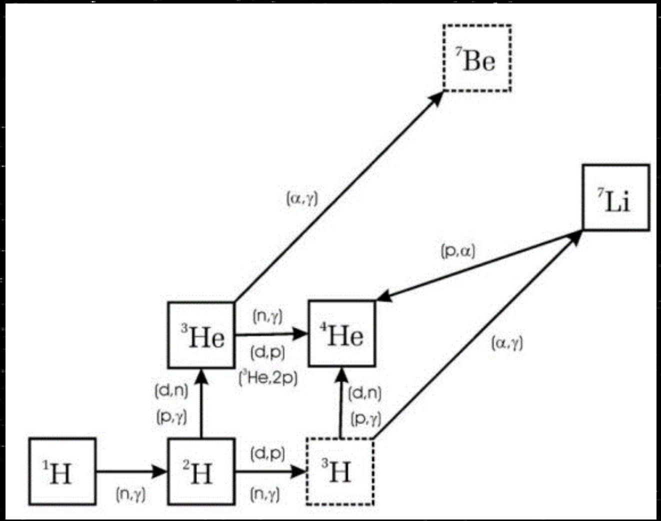
Before recombination, at T>3000K

The early Universe





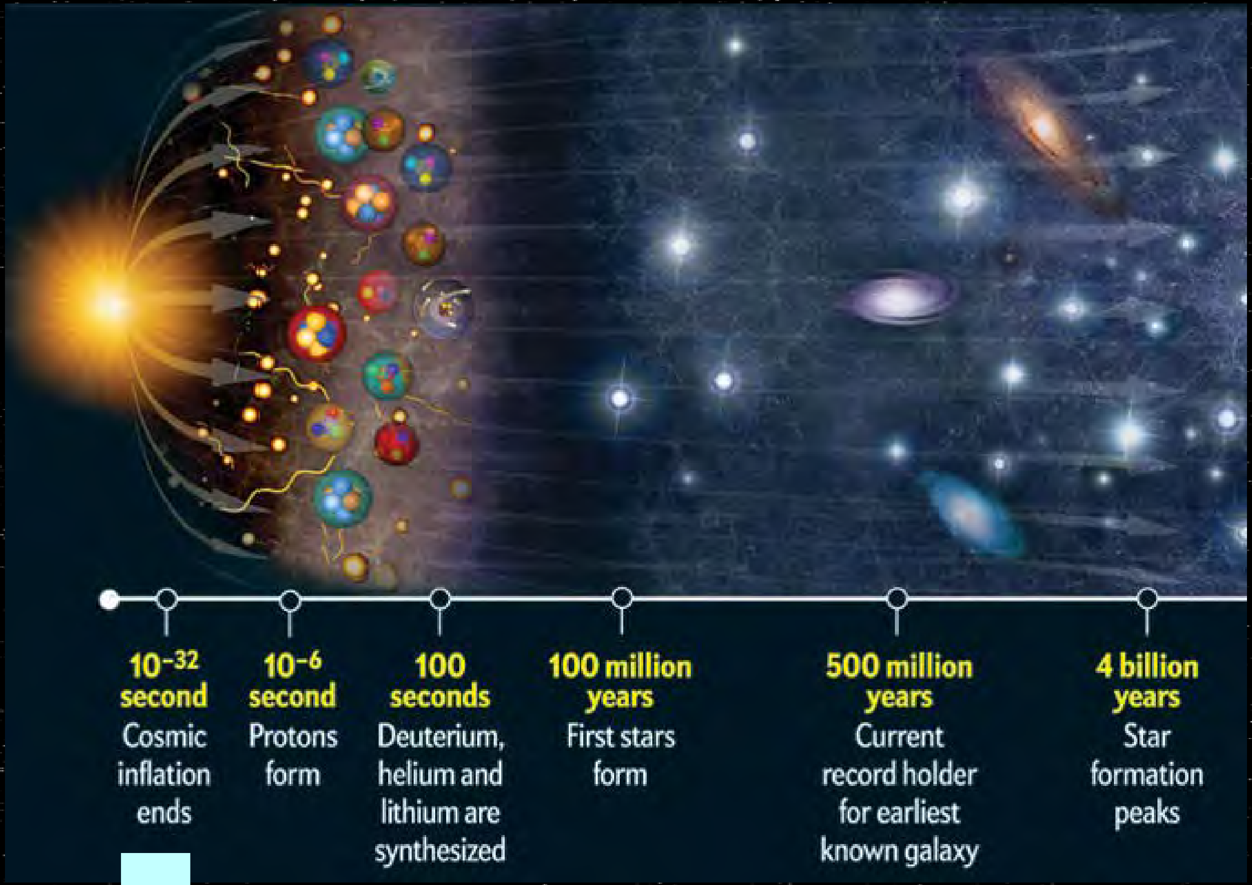




In the first three minutes, light nuclei formed from protons and neutrons

Primordial Nucleosynthesis provide very precise estimates of abundances -> bounds on Ωb

The early Universe

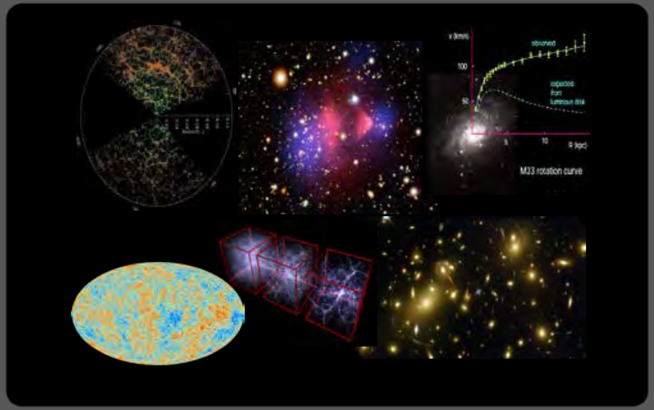


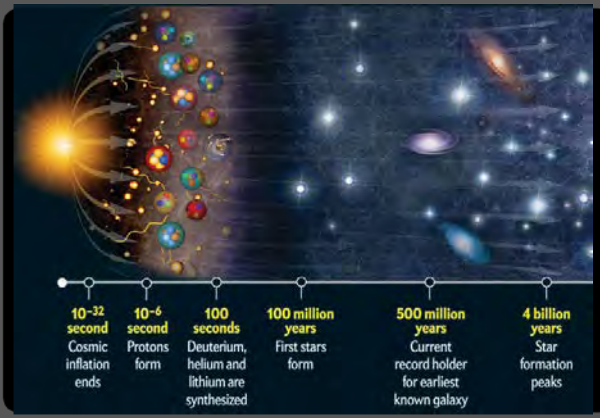
The ultimate Particle Physics laboratory

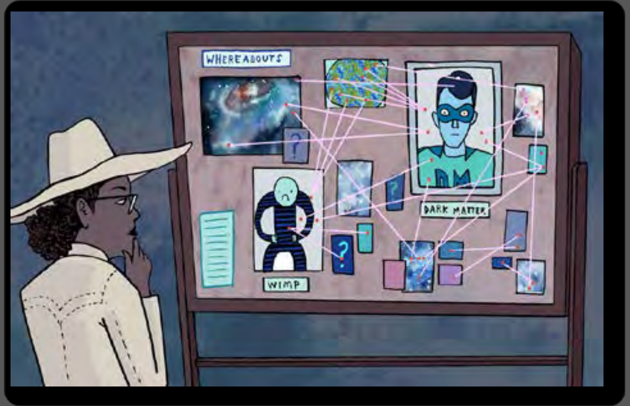
The energies corresponding to the early Universe are out of the reach of accelerators

Physics beyond our present theory could have produced “relic particles” able to explain the DARK MATTER

OUTLINE







Evidences on DARK MATTER come from astrophysics and cosmology

The early Universe picture

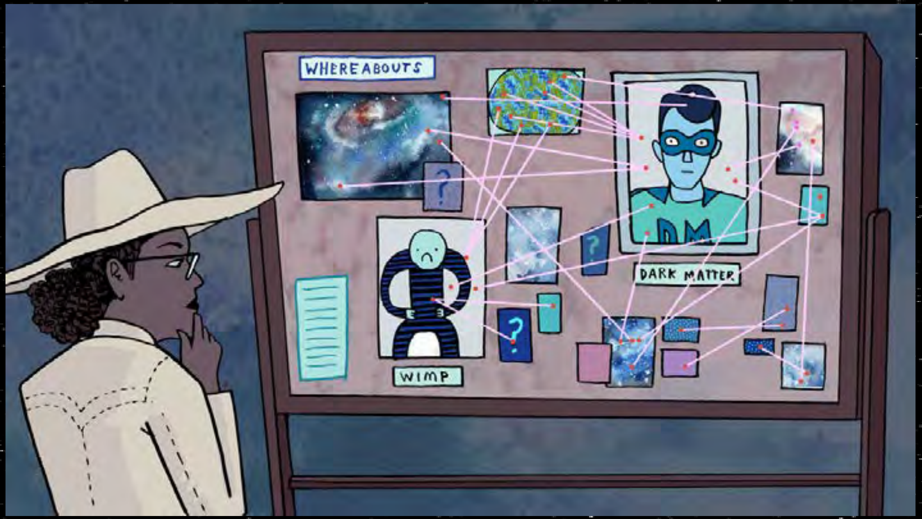
DARK MATTER CANDIDATES
from the point of view of a nuclear/particle physicist

PARTICLE DARK MATTER CANDIDATES

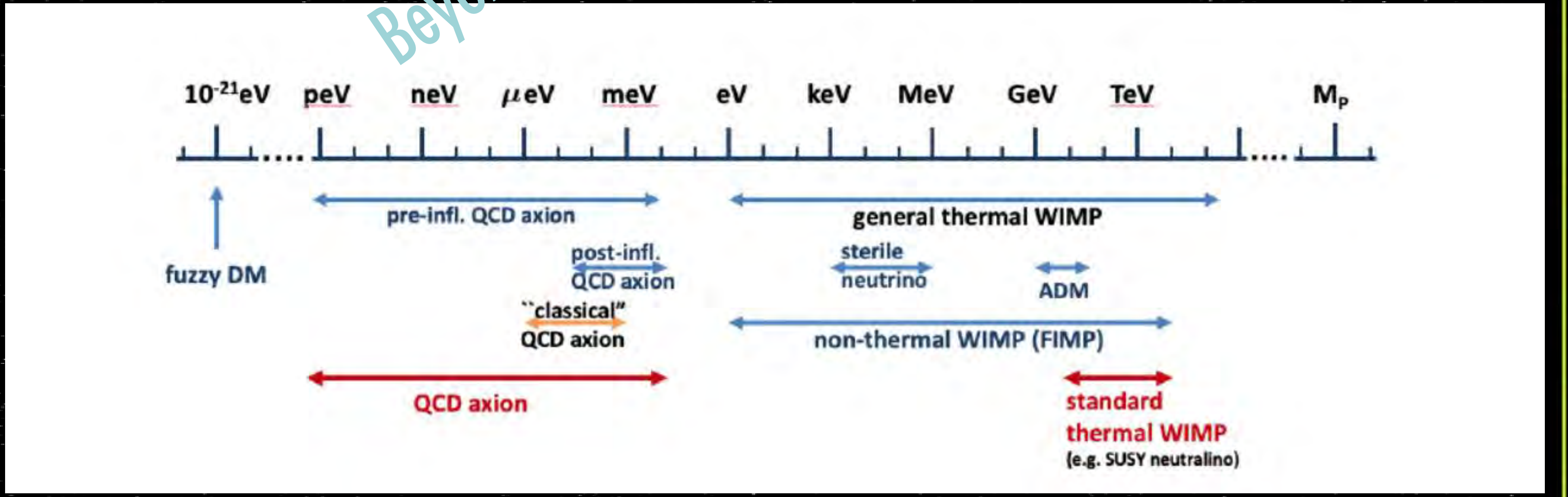
A few "generic" properties:

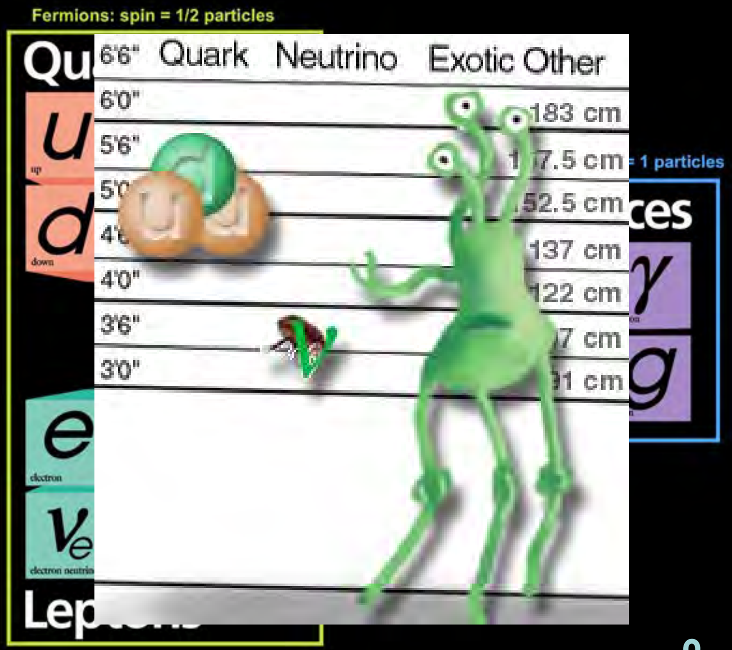
- massive
- non-baryonic
- neutral (or milli-charged)
- stable (or very long lived)
- non relativistic when structures formed (cold/warm)
- only gravitationally interacting or very weakly interacting (EW/new couplings)

Beyond the Standard Model of Particle Physics



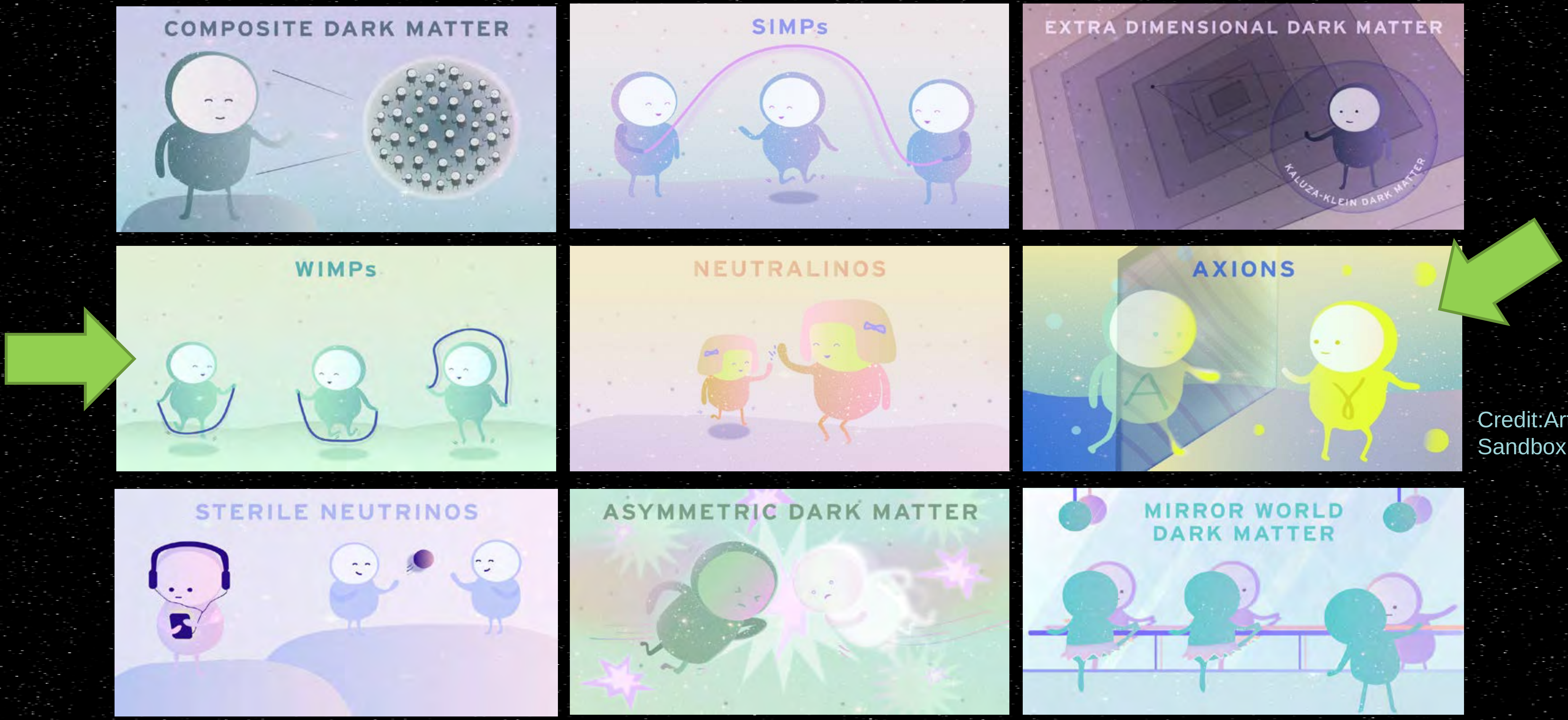
Credit:Artwork by Sandbox Studio, Chicago with Corinne Mucha





Covering many orders of magnitude in mass and cross section

PARTICLE DARK MATTER CANDIDATES

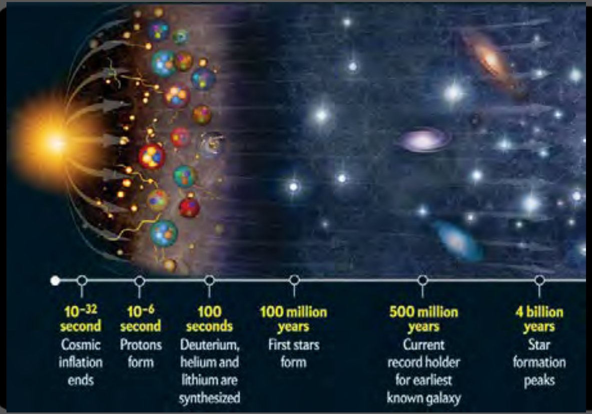


Credit:Artwork by
Sandbox Studio, Chicago

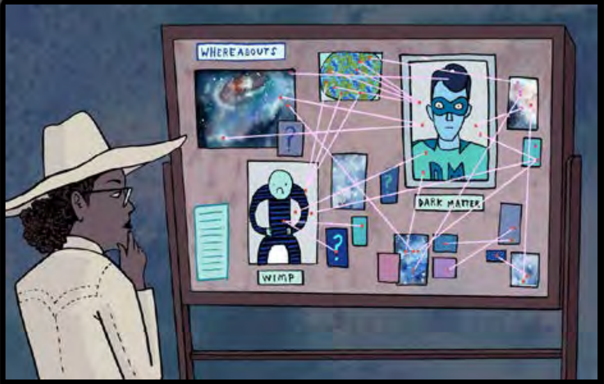
Covering many orders of magnitude in mass and cross section

OUTLINE

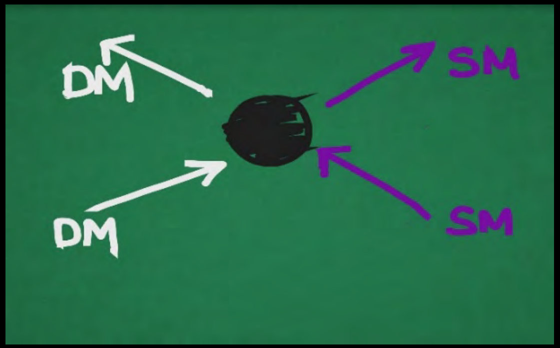
Evidences on DARK MATTER come from astrophysics and cosmology



The early Universe picture



DARK MATTER CANDIDATES
from the point of view of a nuclear/particle physicist



STRATEGIES TO SEARCH FOR PARTICLE DARK MATTER

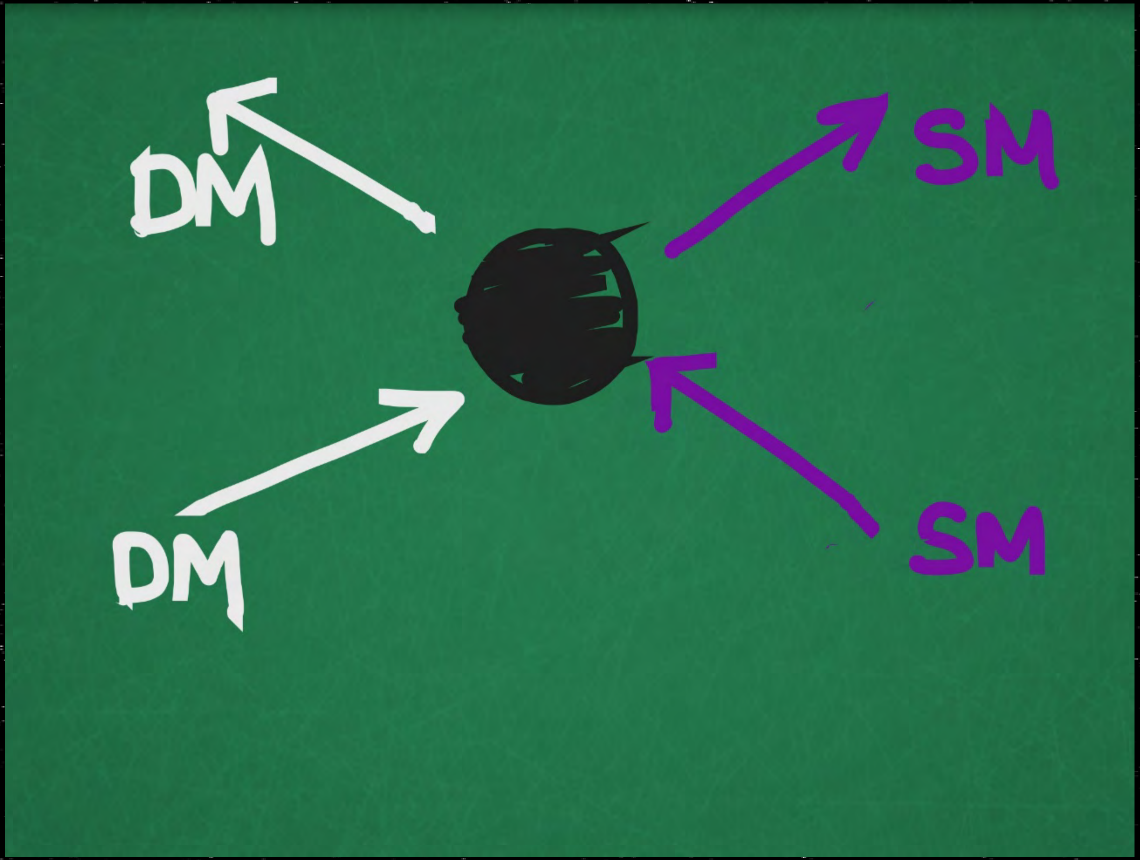
STRATEGIES TO SEARCH FOR PARTICLE DARK MATTER

Without assumptions on the coupling between DM and SM particles, BUT THIS COUPLING EXISTS although WEAK

-Searching for new particles at accelerators

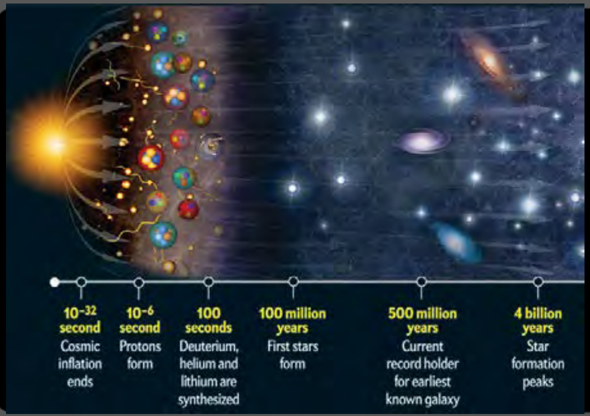
-Indirect detection of the products coming from DM annihilation or decay

-Direct detection of the galactic dark matter

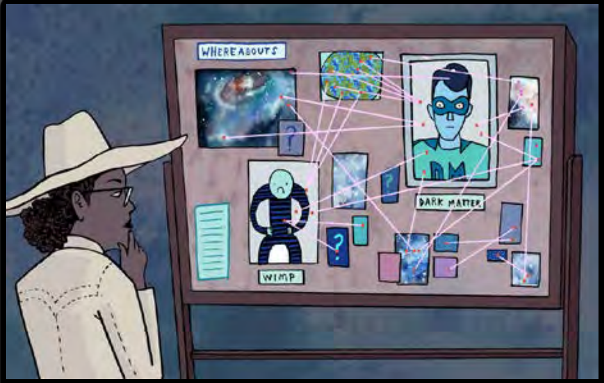


COMPLEMENTARY – RESULTS FROM THE THREE APPROACHES SHOULD BE COMBINED … BUT STRONG MODEL-DEPENDENCIES

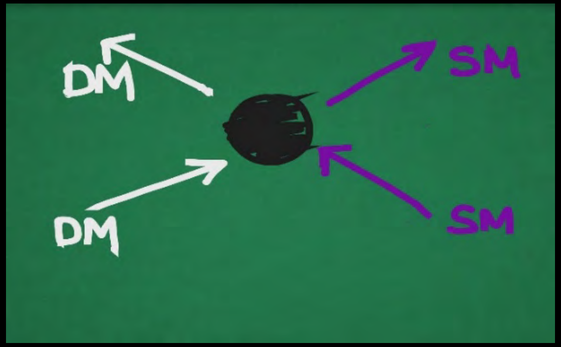
OUTLINE



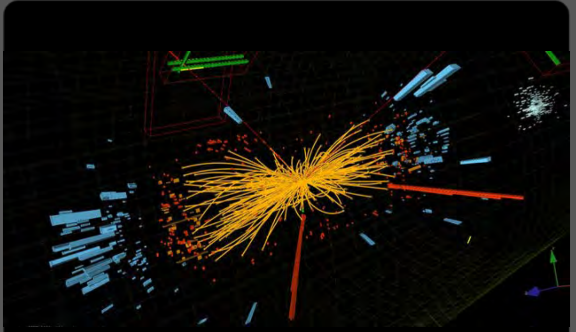
The early Universe picture



DARK MATTER CANDIDATES
from the point of view of a nuclear/particle physicist



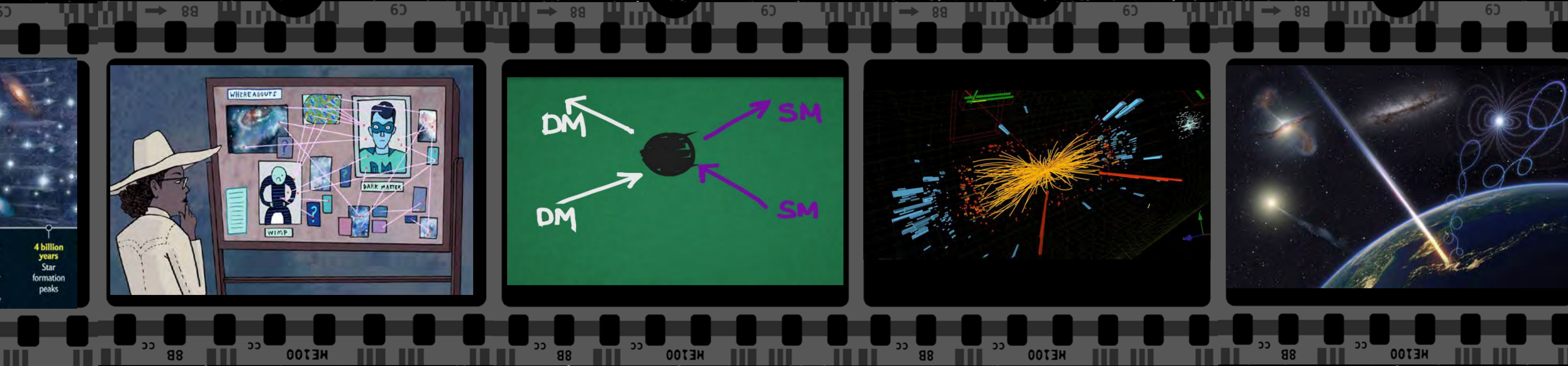
STRATEGIES TO SEARCH FOR PARTICLE DARK MATTER



Search for new particles at accelerators -> DARK MATTER PRODUCTION

Beyond Standard Model Physics

OUTLINE



DARK MATTER CANDIDATES
from the point of view of a nuclear/particle physicist

STRATEGIES TO SEARCH FOR PARTICLE DARK MATTER

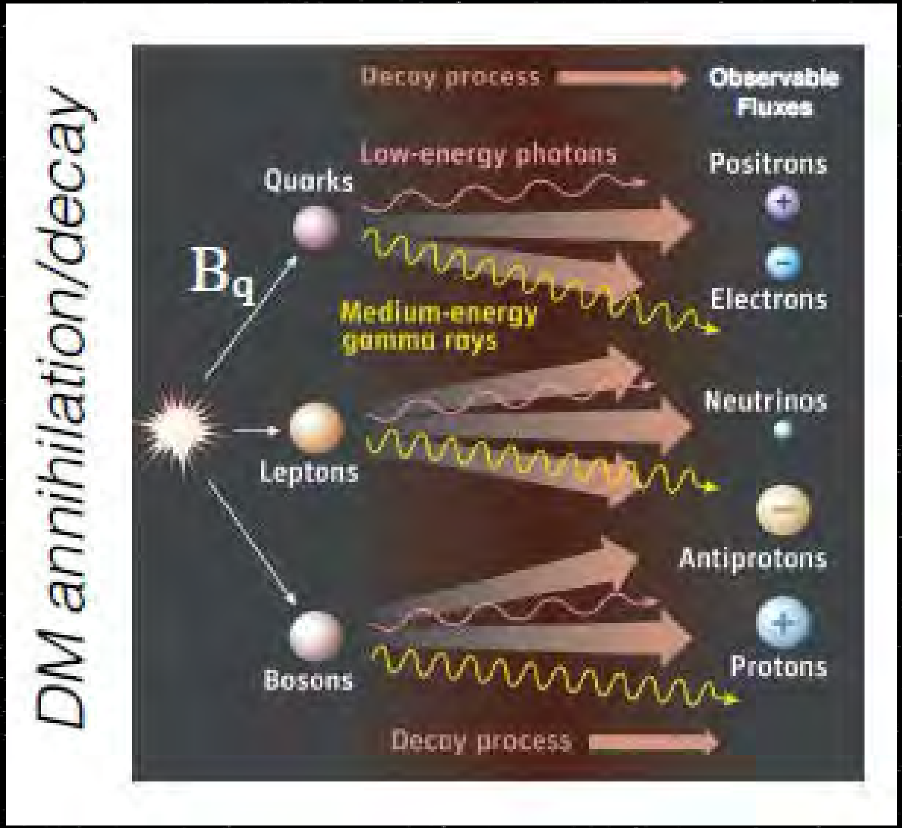
Search for new particles at accelerators -> DARK MATTER PRODUCTION

Beyond Standard Model Physics

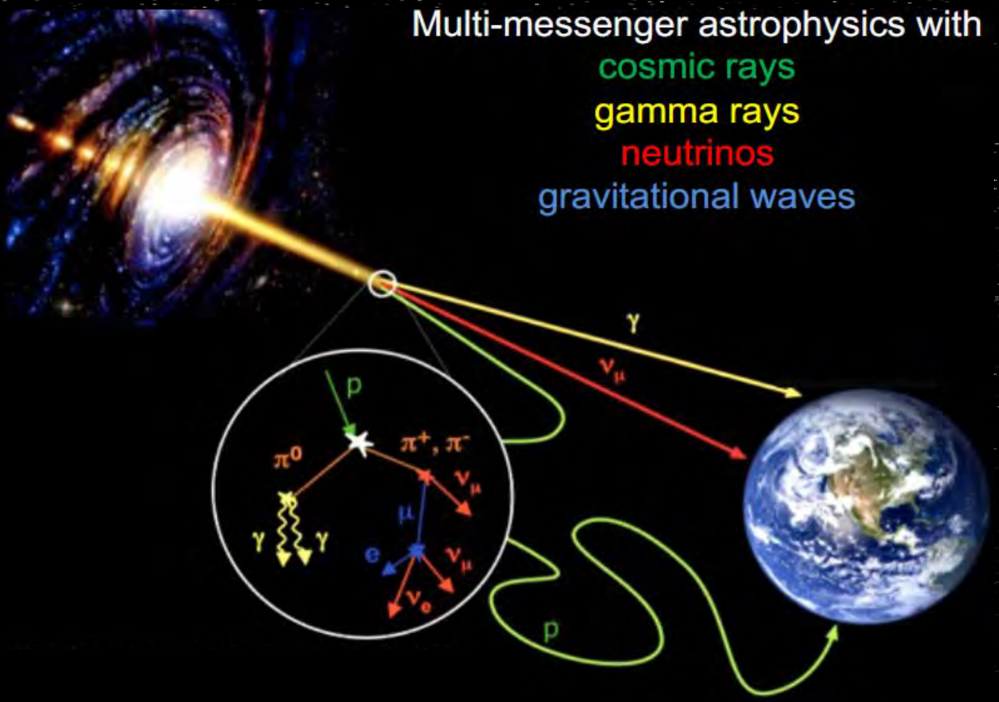
INDIRECT DETECTION
Searching for the products of the annihilation or decay of DARK MATTER

SIGNALS FROM DM ANNIHILATIONS / DECAY

Different channels to be considered / Different detection strategy
Strongly dependent on the DM Particle Model
Many uncertainties in the expected fluxes



But also, many other astrophysical backgrounds to be taken into consideration



SIGNALS FROM DM ANNIHILATIONS / DECAY

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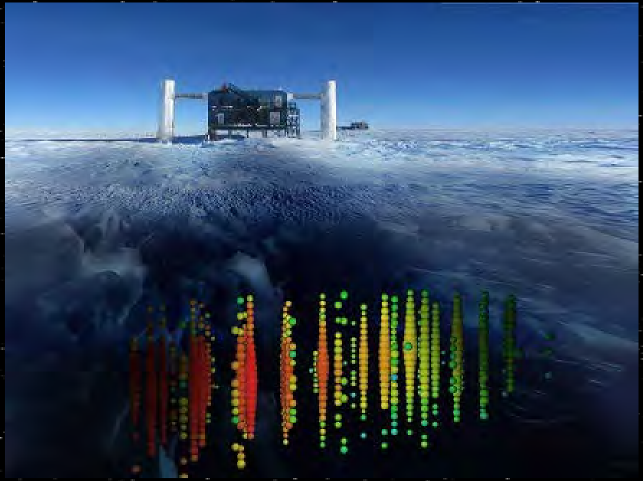
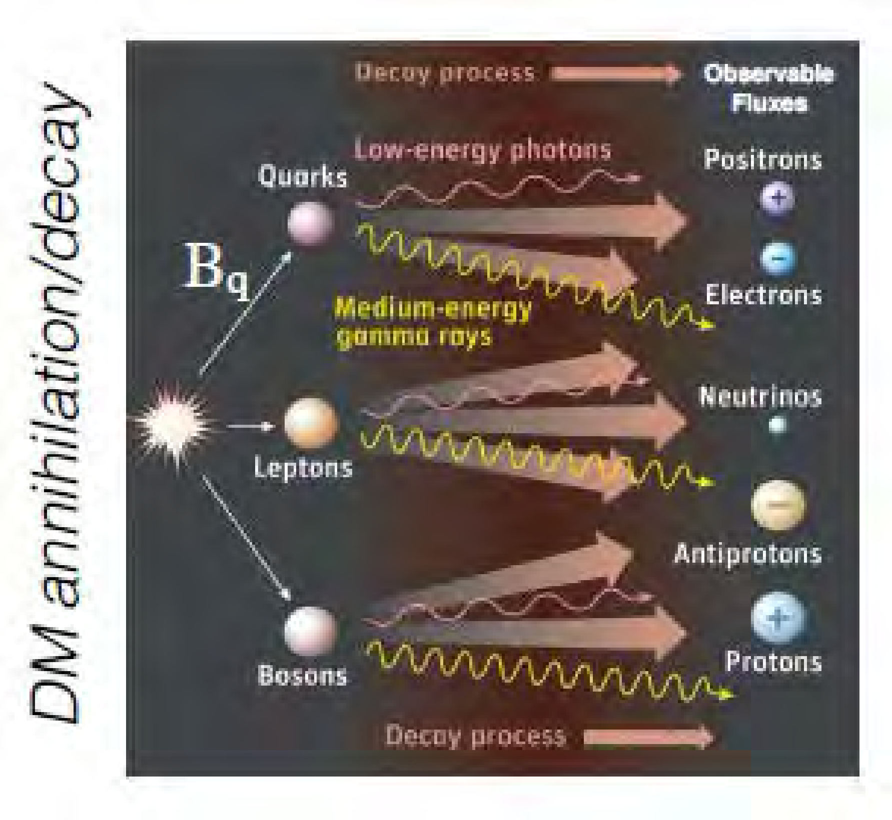
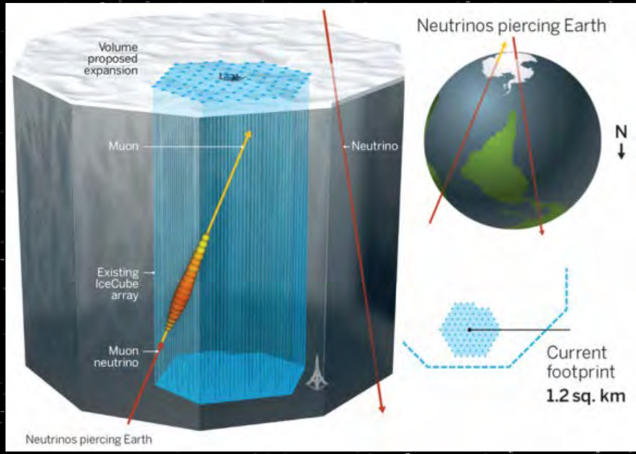
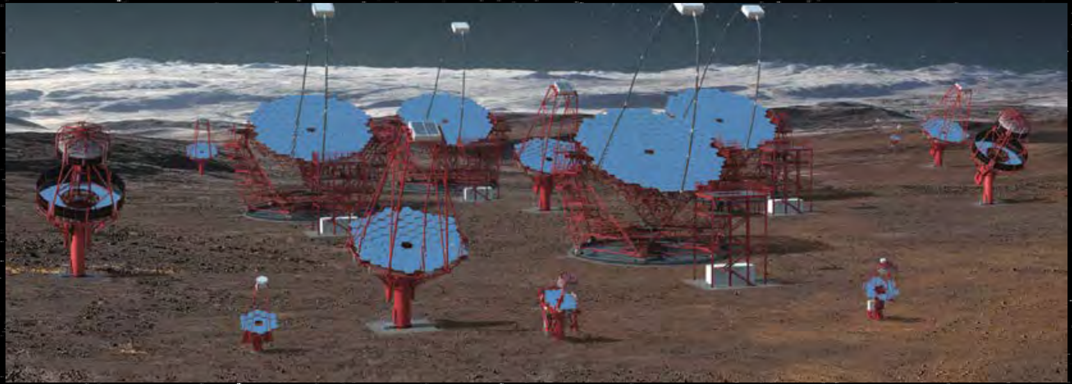




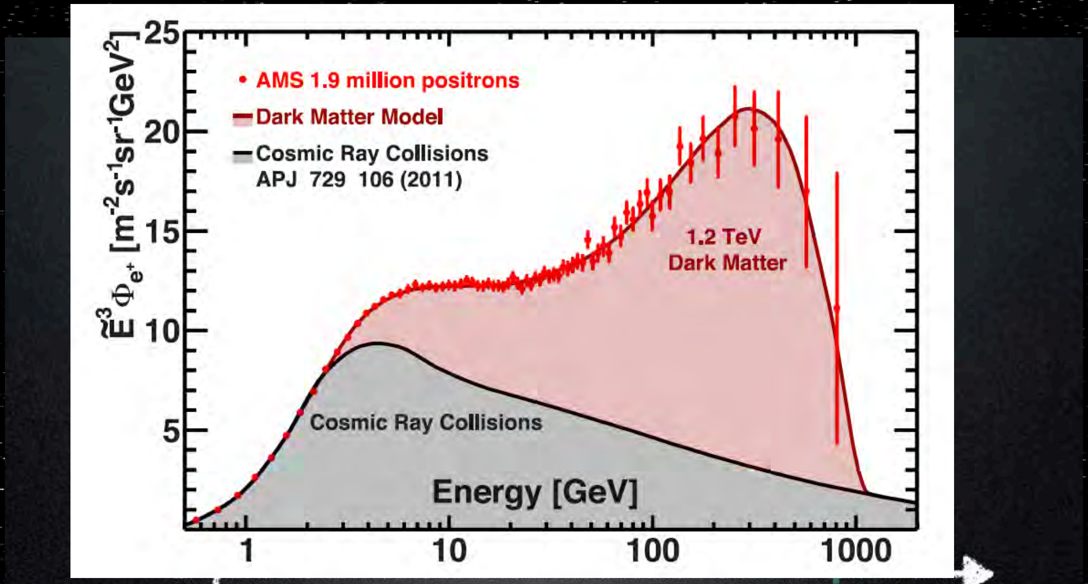




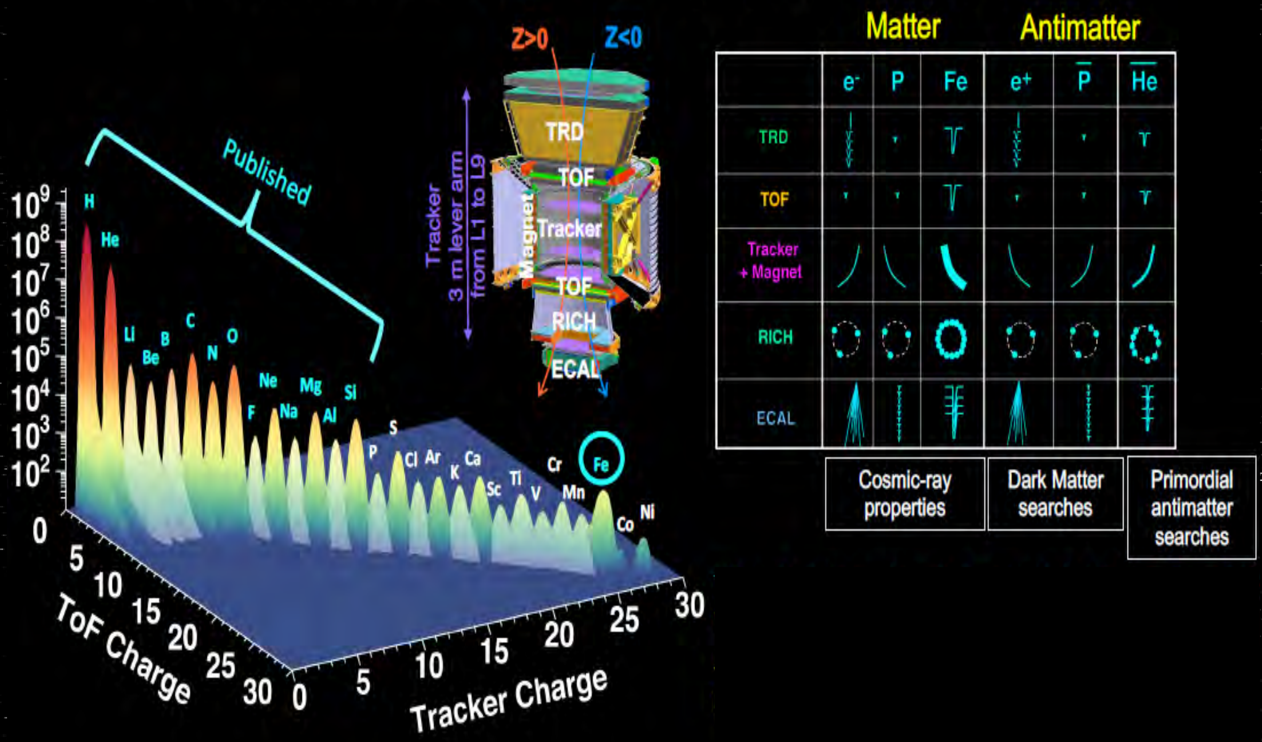
CHARGED PARTICLES SEARCHES

Instruments in Space

Still many uncertainties on sources of cosmic rays, and propagation
Strongly dependent on modelling of backgrounds to extract information from DM annihilation



Positron Excess



OUTLINE

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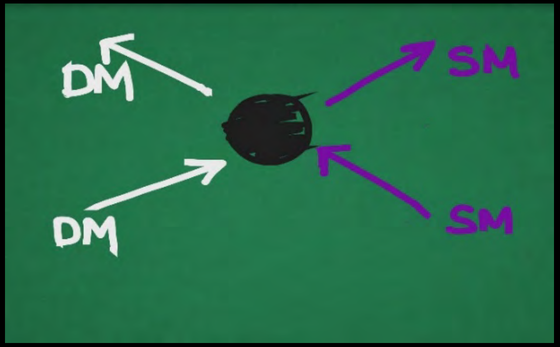
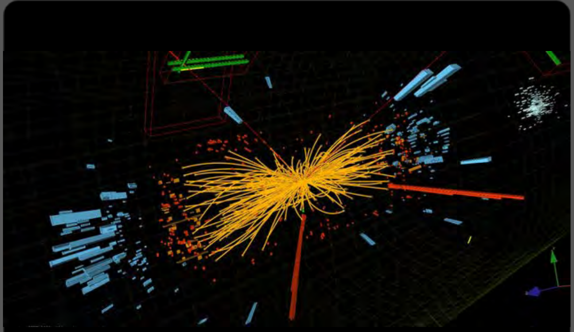


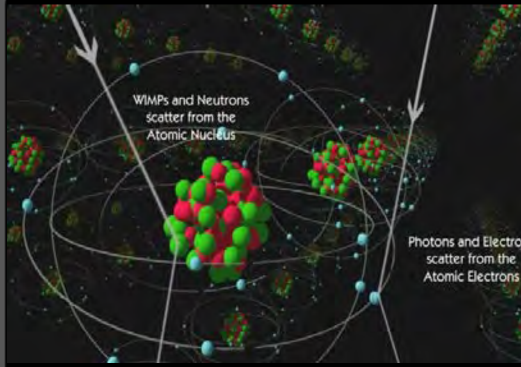
STRATEGIES TO SEARCH FOR PARTICLE DARK MATTER



Search for new particles at accelerators -> DARK MATTER PRODUCTION

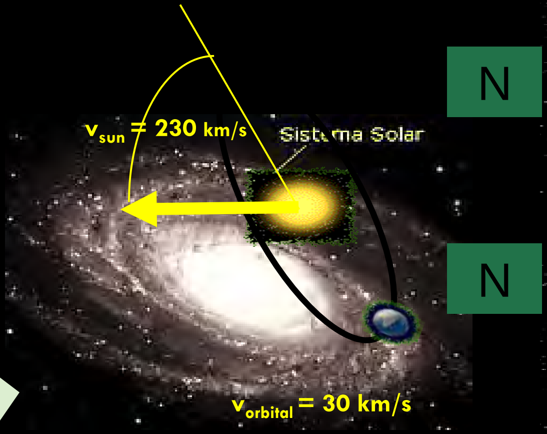
Beyond Standard Model Physics

INDIRECT DETECTION
Searching for the products of the annihilation or decay of DARK MATTER

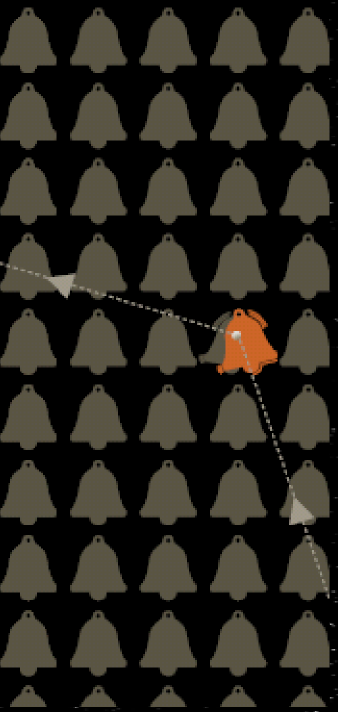


DIRECT DETECTION
Searching for the interaction of DARK MATTER in convenient detectors placed underground

DIRECT DETECTION OF DARK MATTER

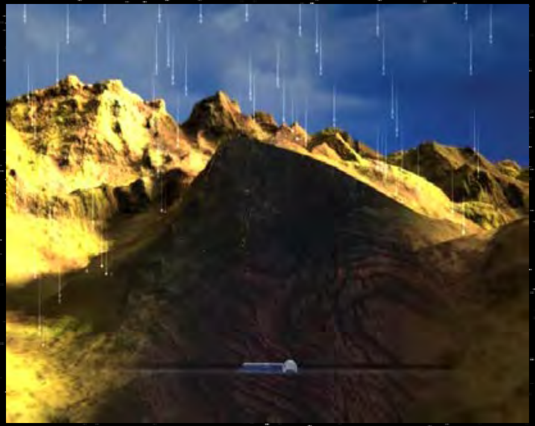


Signatures of a Dark Matter interaction are very convenient for a positive result

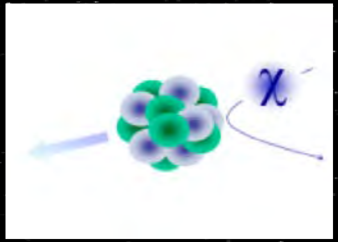


Availability of very sensitive and radiopure particle detectors

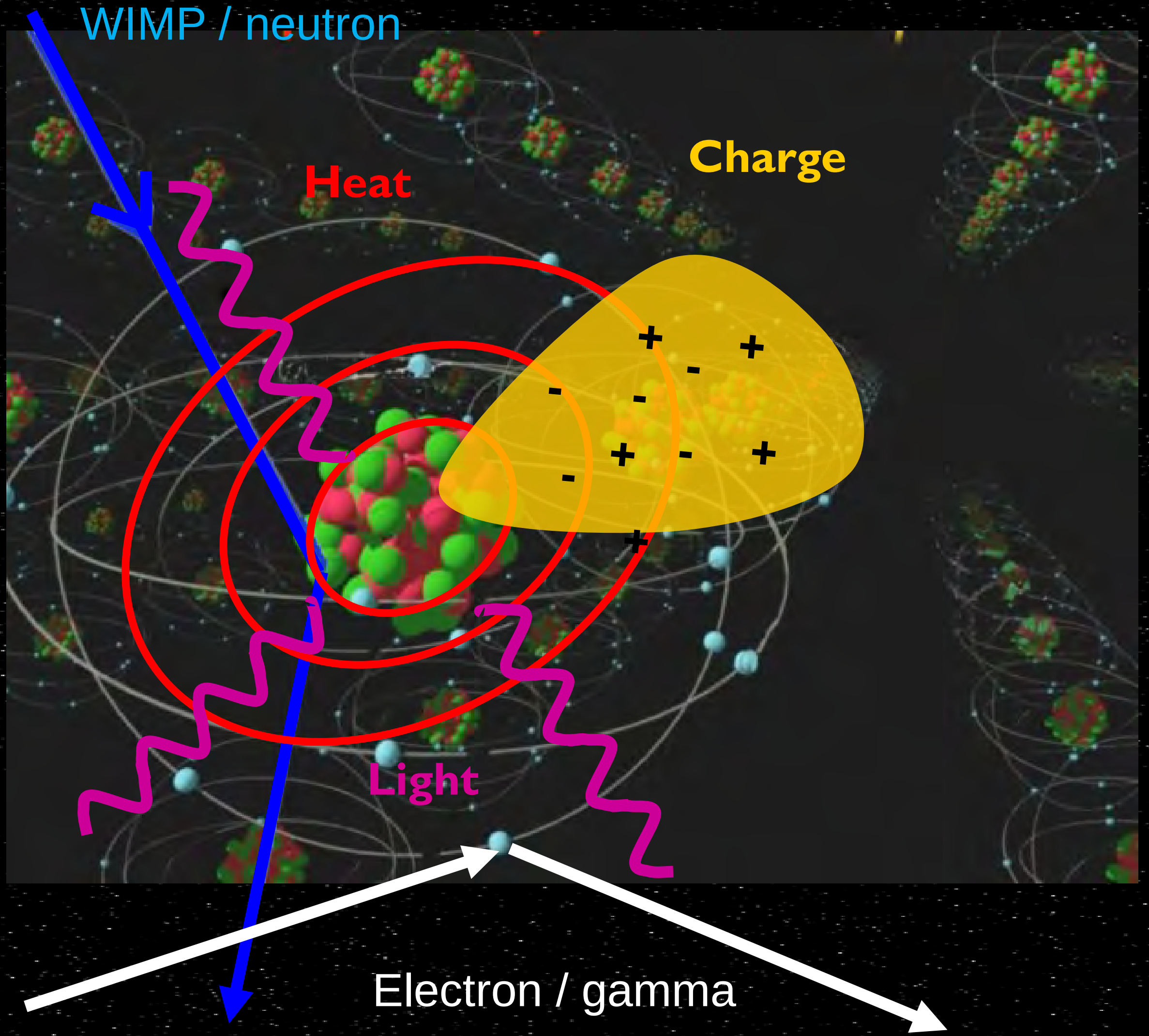
Experiments have to be shielded against all possible backgrounds and profit from active background rejection techniques



WIMPs interact (although weakly) with ordinary matter



DETECTION TECHNIQUES APPLIED IN DIRECT DARK MATTER SEARCHES



Energy conversion into VISIBLE signal is strongly dependent on the interaction mechanism, incident particle and target

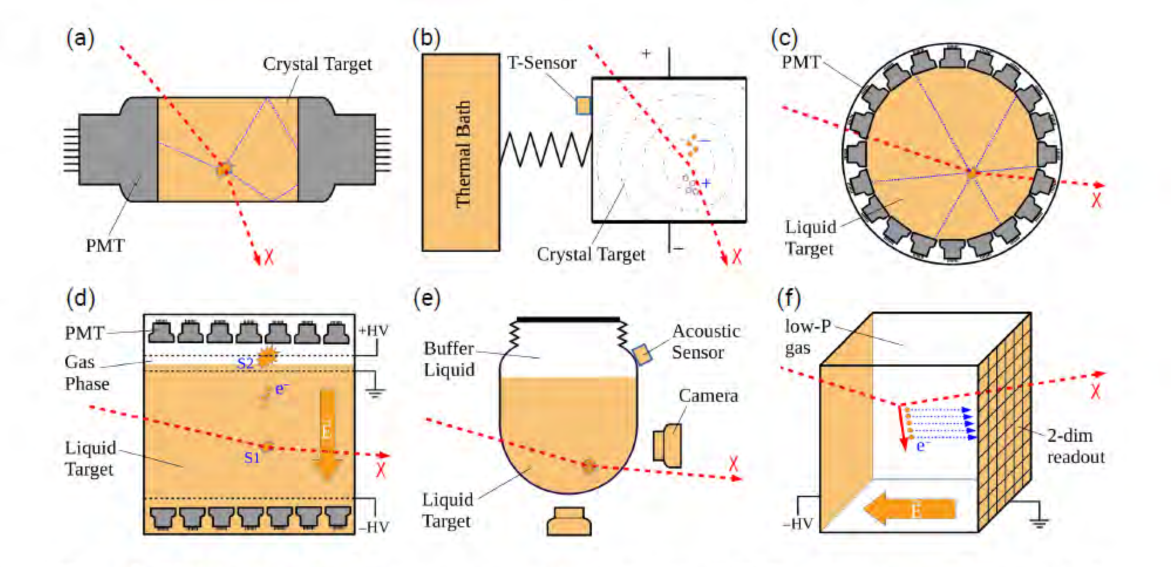
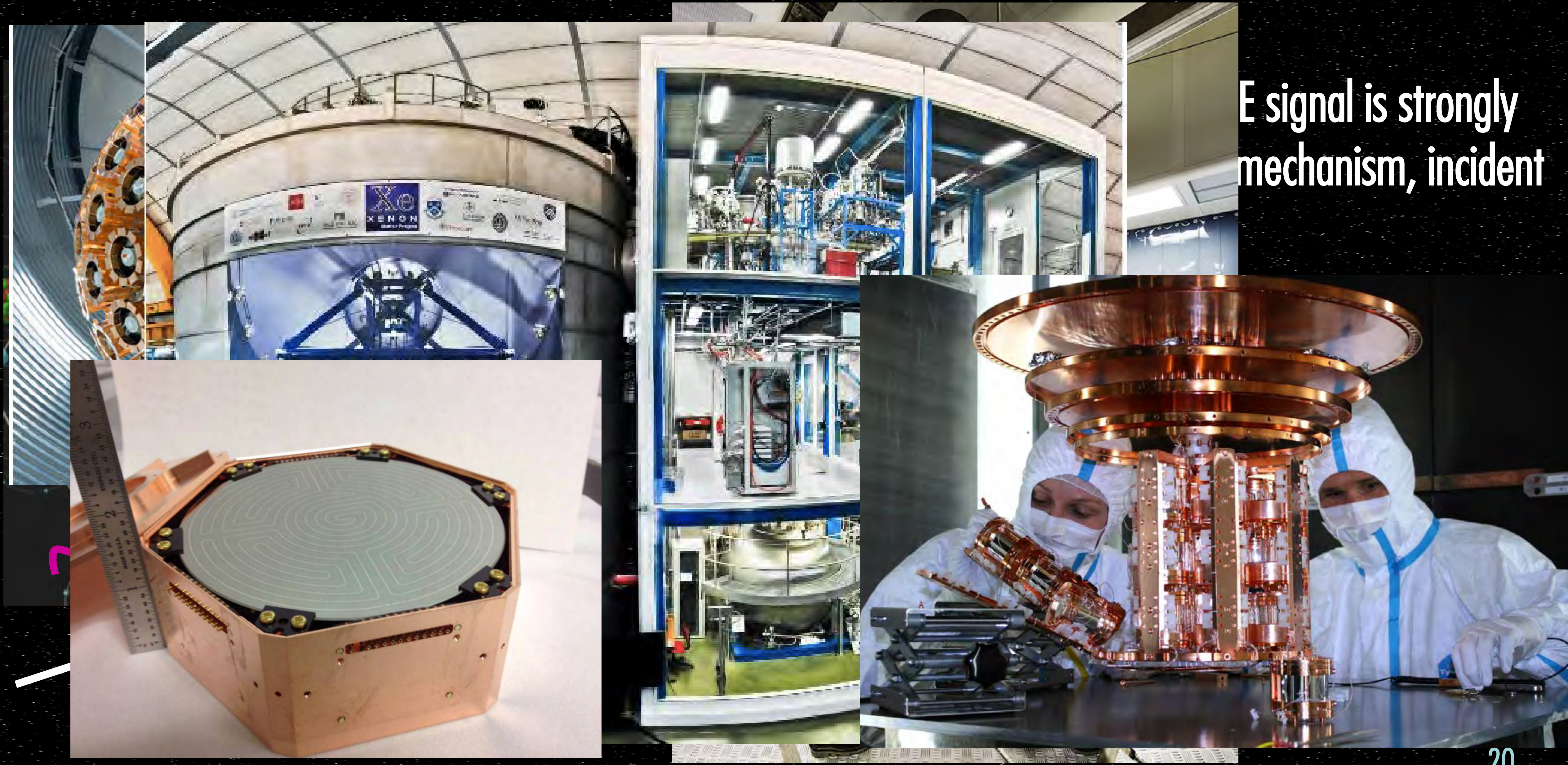


Figure 2: Working principle of common detector types for the direct WIMP search: (a) scintillating crystal, (b) bolometer (here with additional charge-readout), (c) single-phase and (d) dual-phase liquid noble gas detectors, (e) bubble chamber, (e) directional detector. Images adapted from [113].

DETECTION TECHNIQUES APPLIED IN DIRECT DARK MATTER SEARCHES



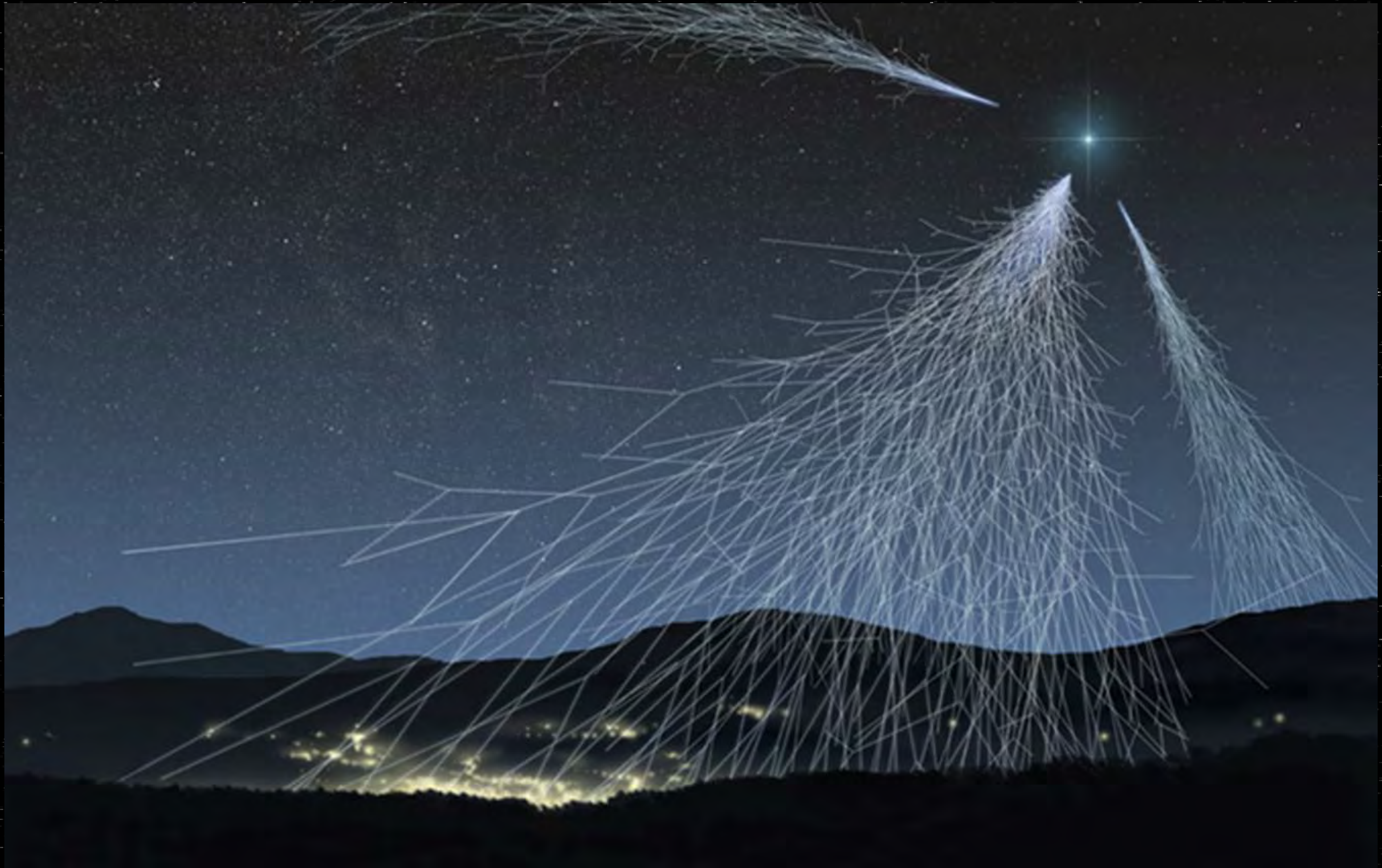
E signal is strongly
mechanism, incident

BACKGROUND – INTERFERENCE OF OTHER PARTICLE INTERACTIONS

DIRECT DETECTION OF DARK MATTER

Background signals interferring with WIMP detection come from

-COSMIC Rays



DIRECT DETECTION OF DARK MATTER

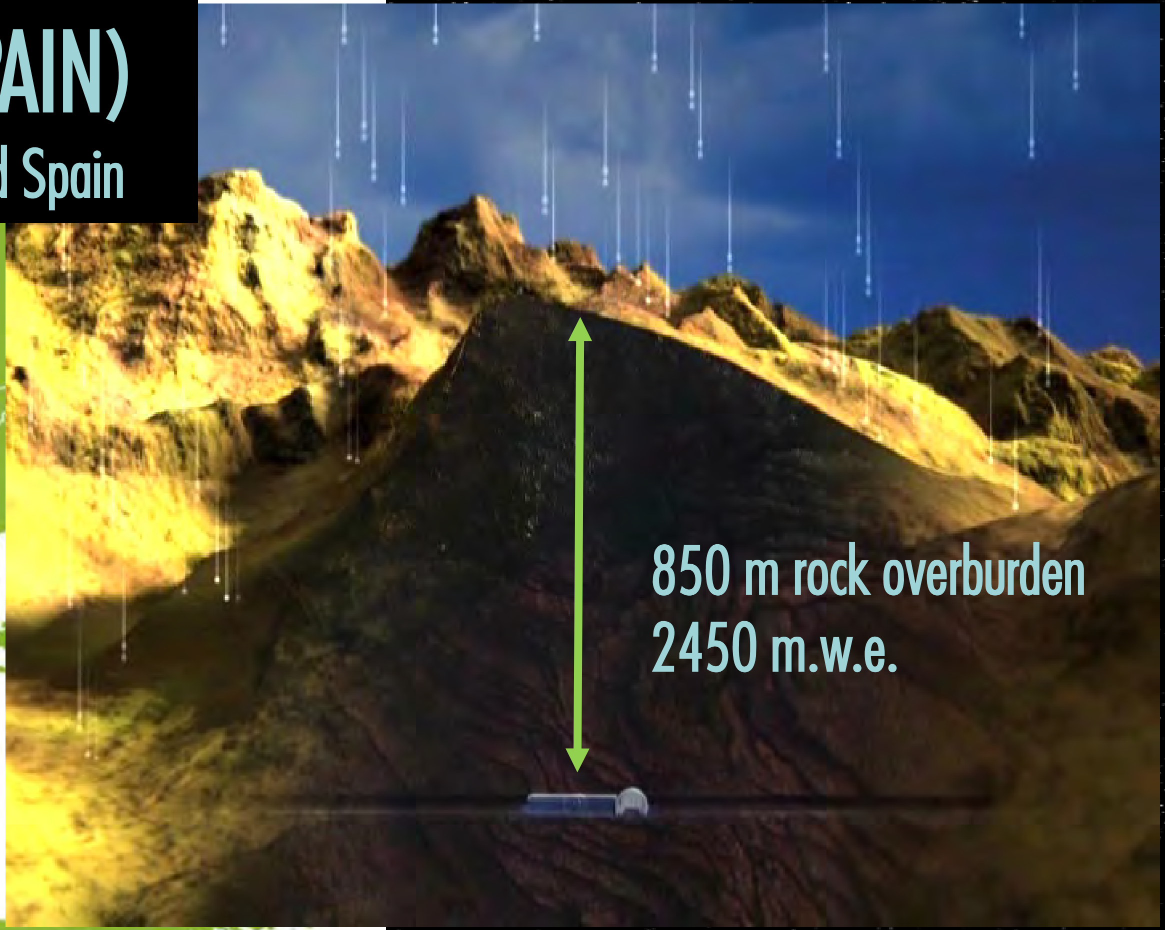
Background signals interferring with WIMP detection come from

-COSMIC Rays

Most of the experiments are carried out in underground laboratories

Canfranc Underground Laboratory (SPAIN)

under the Pyrenees, at the Somport tunnel connecting France and Spain



DIRECT DETECTION OF DARK MATTER

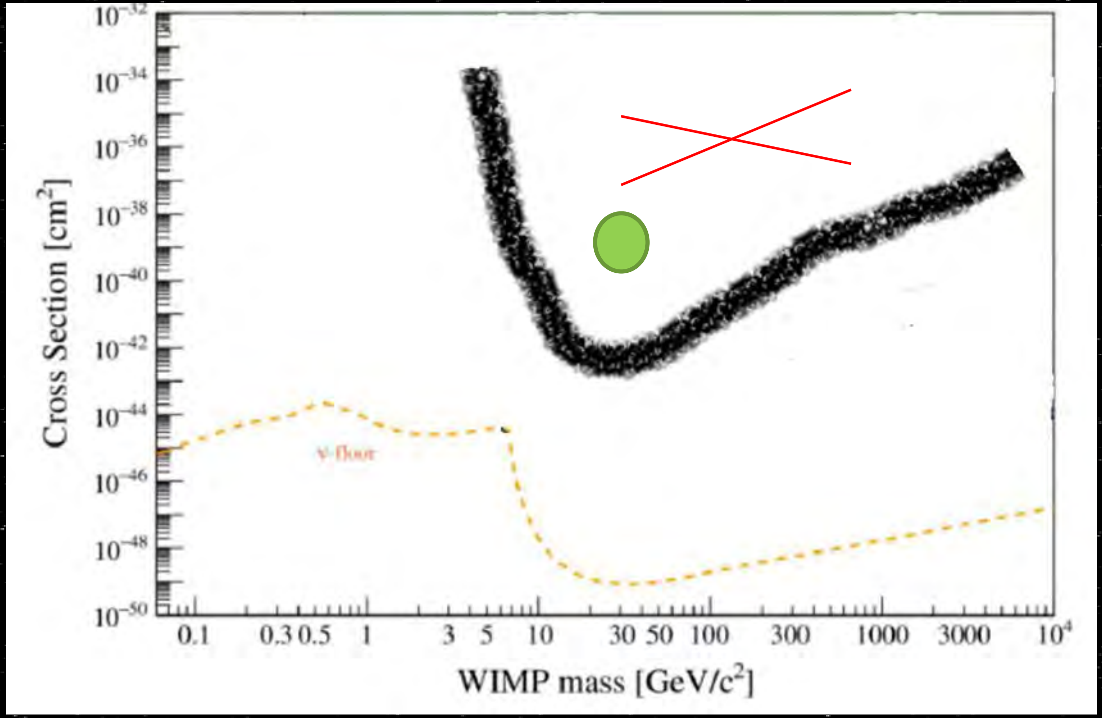
Strong Passive and Active Shielding Strategies have to be applied

Background signals interferring with WIMP detection come from

- -COSMIC Rays
- -Environmental Radioactivity

Sensitivities have been improving in the last 25 years strongly

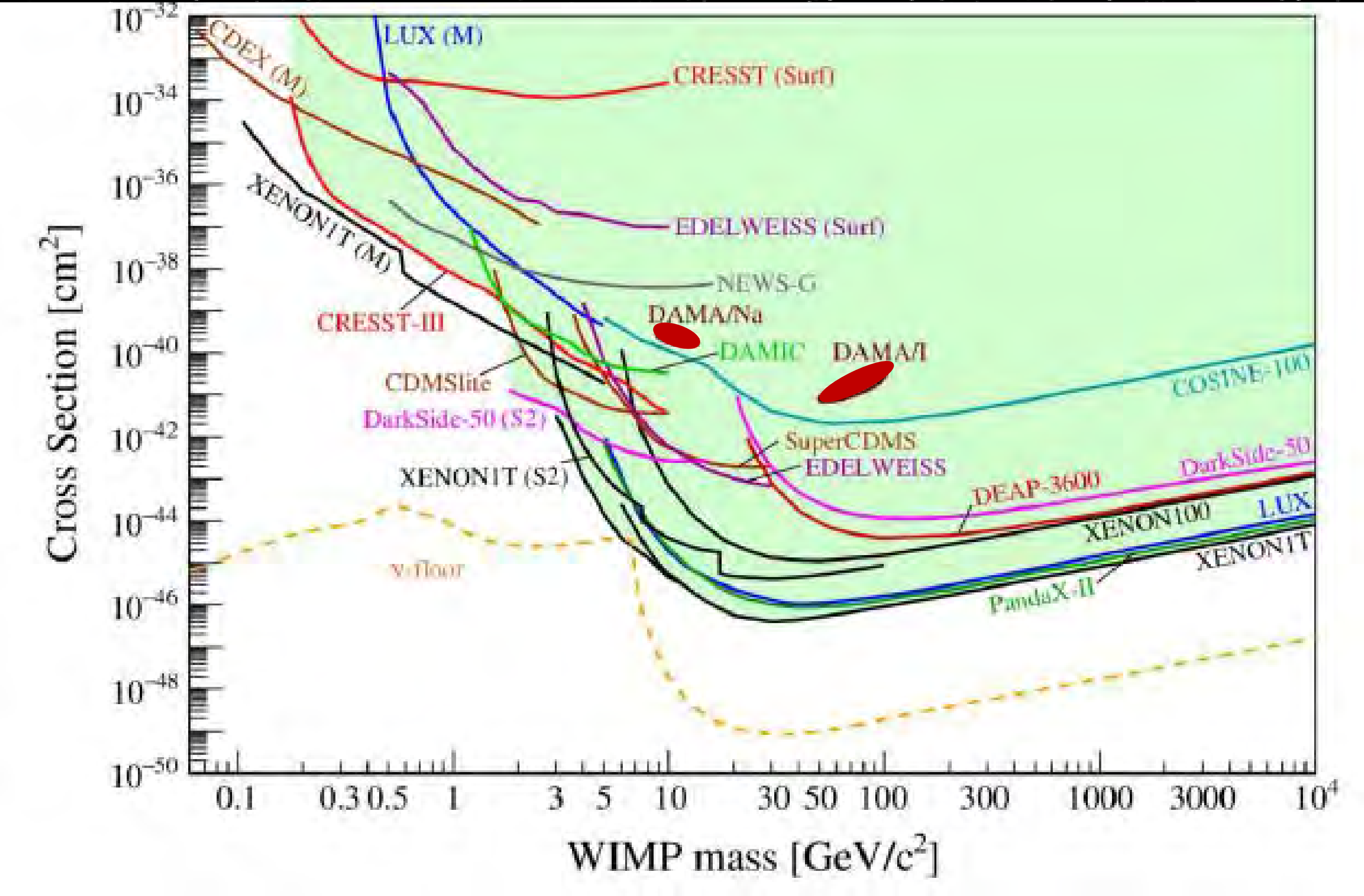
Compatible with expected backgrounds -> allow to rule out particles interacting less weakly



But one experiment accumulating more than 20 years of data, is compatible with DM

ANNUAL MODULATION RESULT PUZZLE

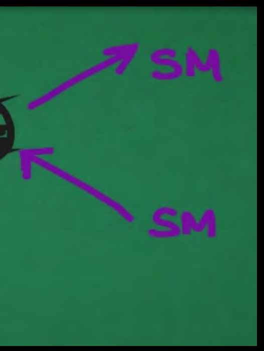
Other much sensitive experiments do not have any hint -> Strong tension even assuming more general halo/interaction models, BUT MODEL – DEPENDENT



Same target would reduce most of the uncertainties and model dependencies !

Direct Detection of Dark Matter – APPEC Committee Report
arXiv:2104.07634

OUTLINE



SEARCH
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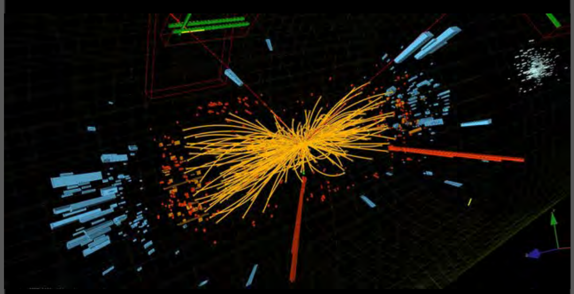
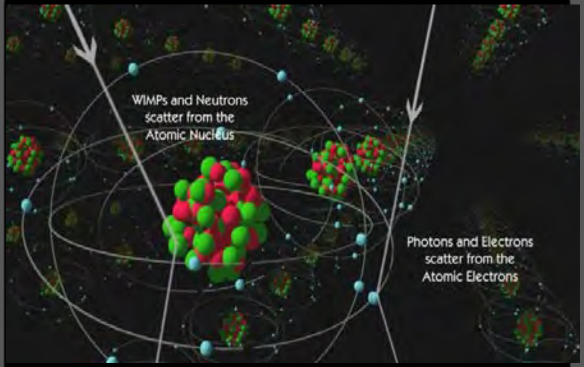


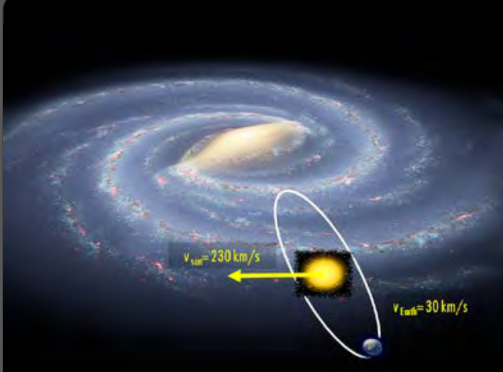
Search for new particles at accelerators -> DARK MATTER PRODUCTION

Beyond Standard Model Physics

INDIRECT DETECTION
Searching for the products of the annihilation or decay of DARK MATTER

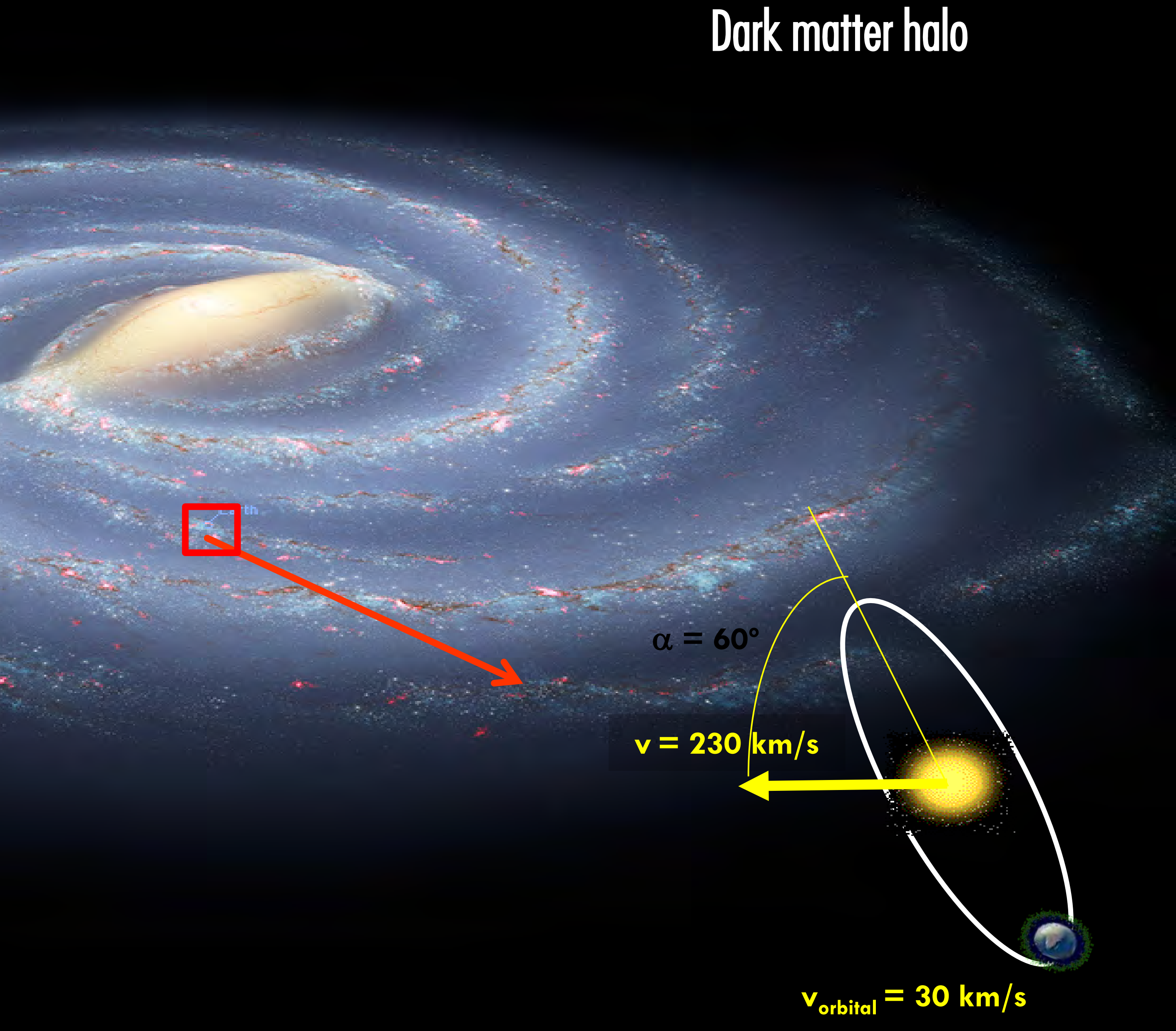


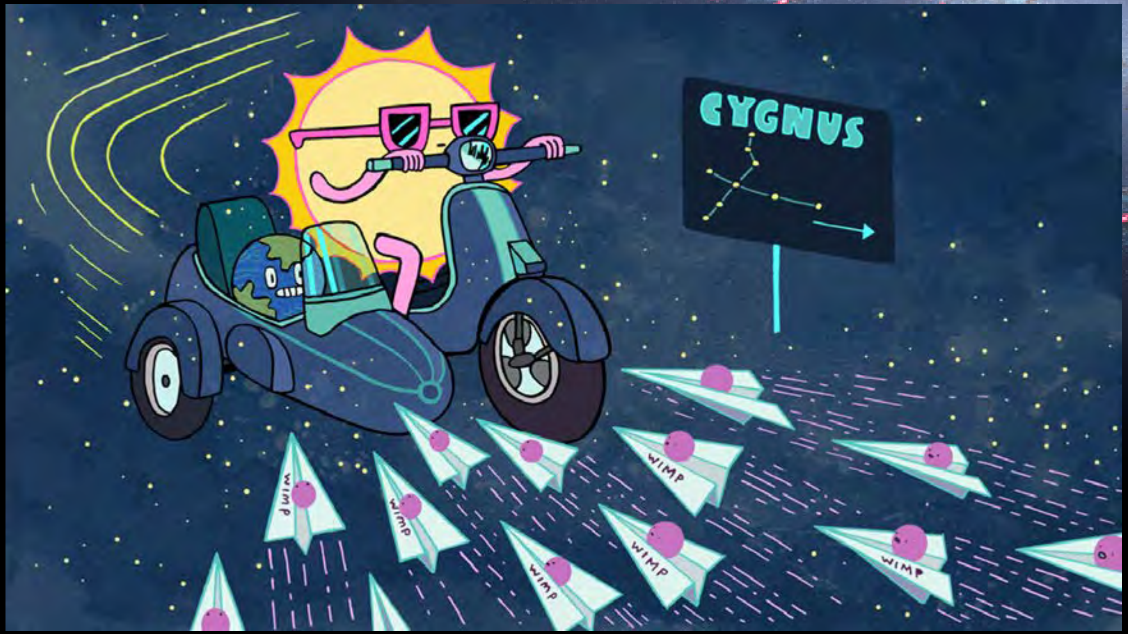
DIRECT DETECTION
Searching for the interaction of DARK MATTER in convenient detectors placed underground



ANNUAL MODULATION SEARCHES
Distinctive signature of GALACTIC PARTICLE DARK MATTER

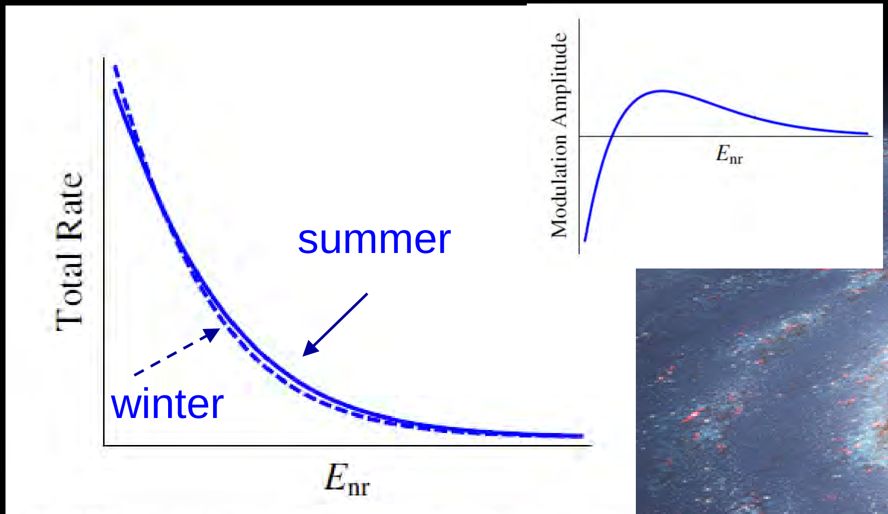
ANNUAL MODULATION IN THE DARK MATTER SIGNAL



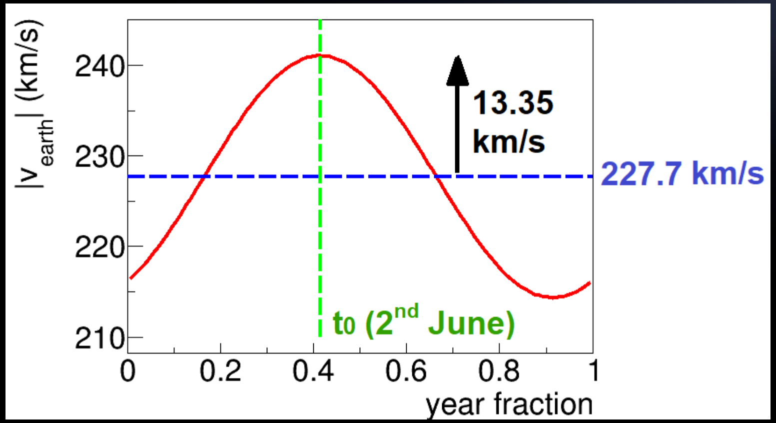


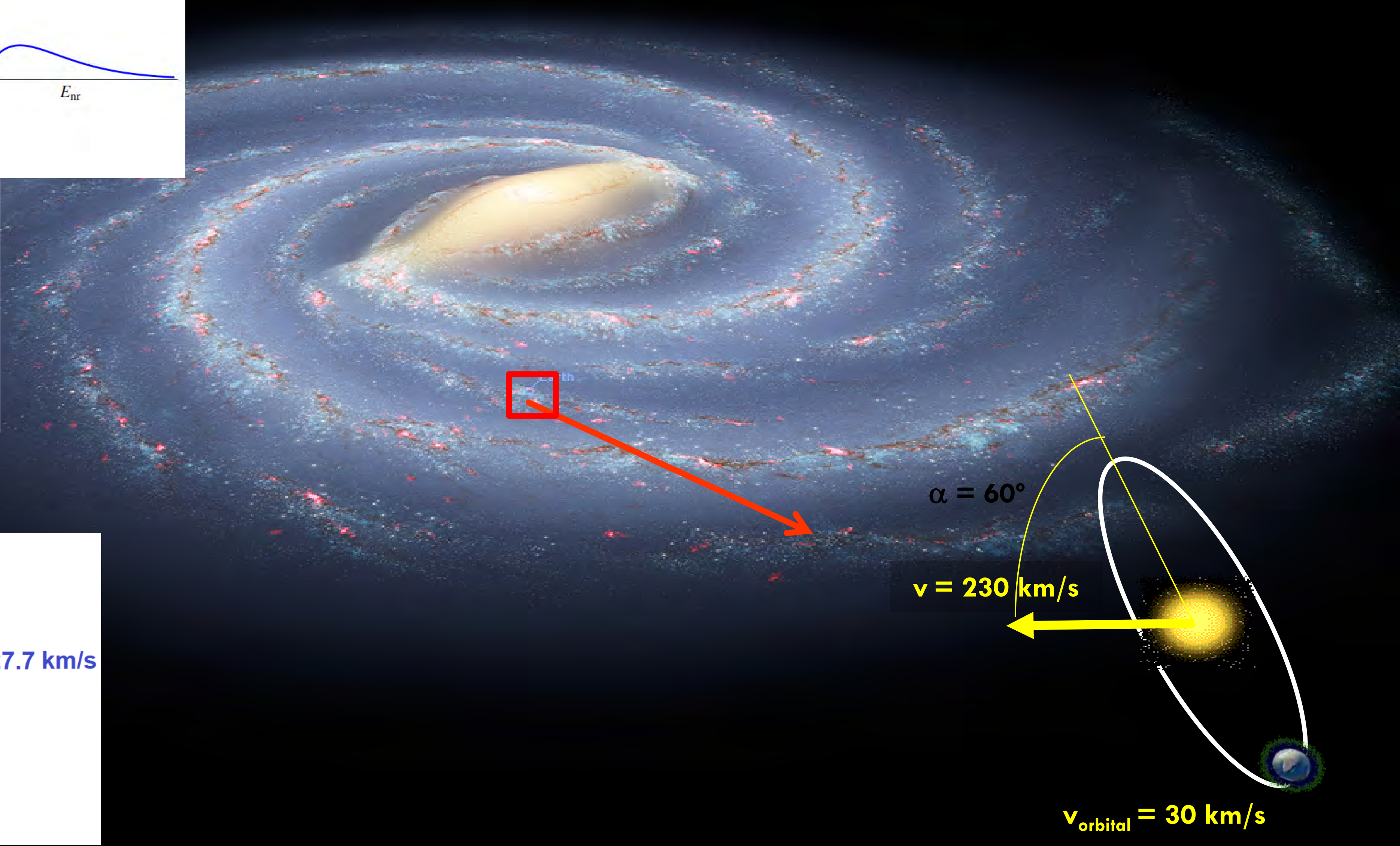
Artwork by Sandbox Studio, Chicago with Corinne Mucha

ANNUAL MODULATION IN THE DARK MATTER SIGNAL



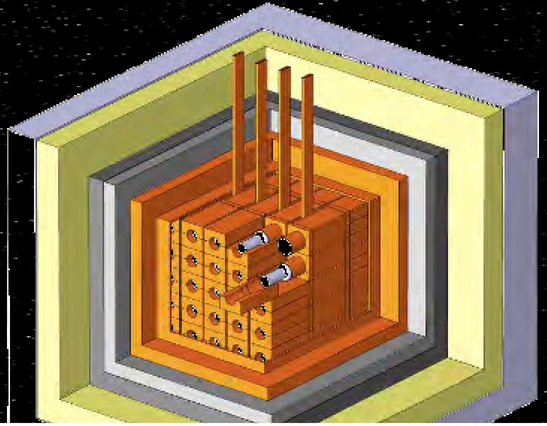
$$S_k(t) = S_{0,k} + S_{m,k} cos\omega(t - t_0)$$



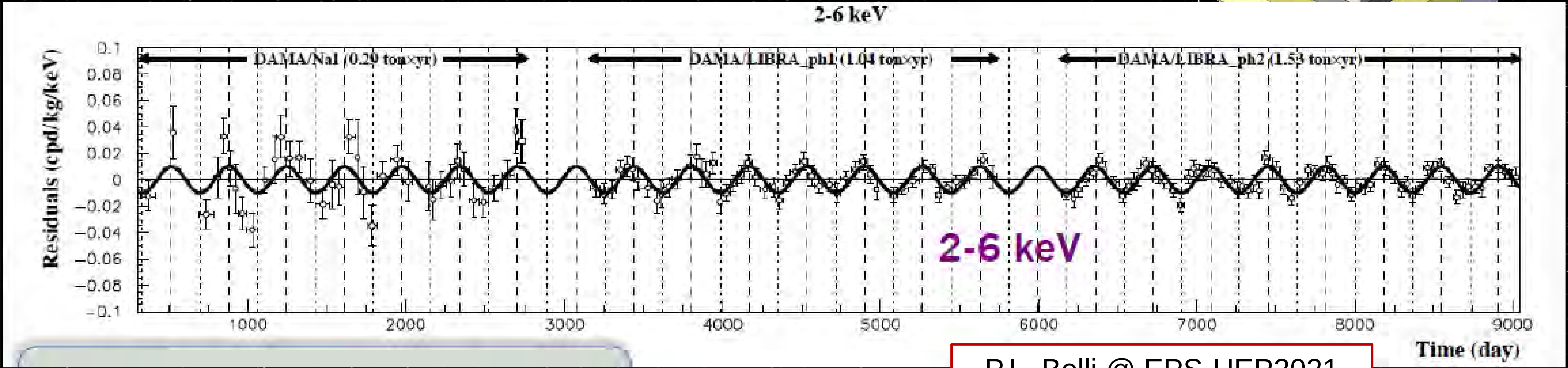


DAMA/LIBRA EXPERIMENT

@ LNGS, Laboratori Nazionali del Gran Sasso, Italy



New data release in July 2021 @ EPS-HEP



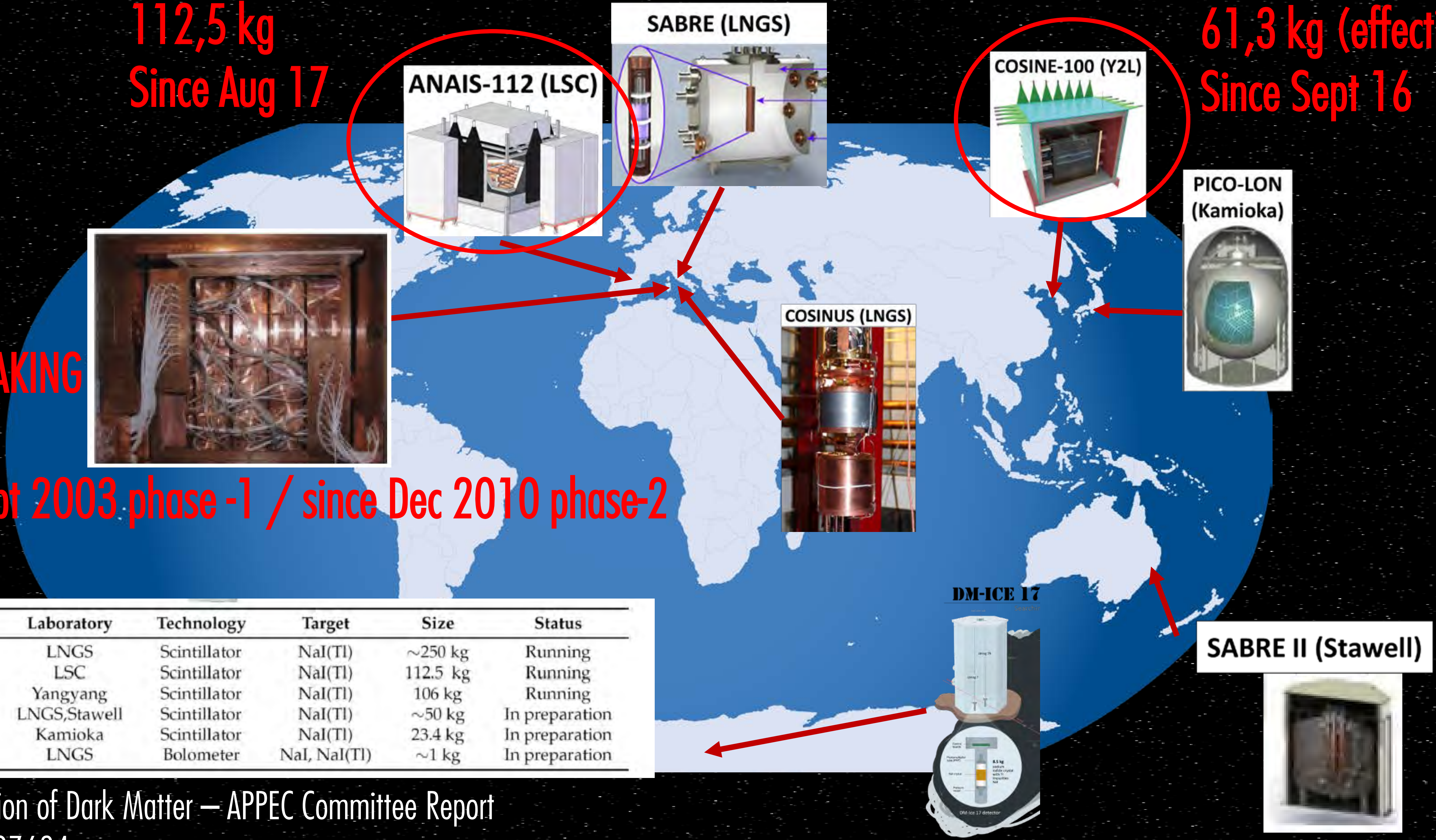
P.L. Belli @ EPS-HEP2021

This signal can be interpreted as produced by WIMPs, but… interpretation is dependent on the DM model!

The data of DAMA/LIBRA favor the presence of a modulation with proper features at 13.4 σ CL (2.86 ton × yr) in the 2-6 keV energy region

IN DATA-TAKING
112,5 kg
Since Aug 17

IN DATA-TAKING
61,3 kg (effective mass)
Since Sept 16

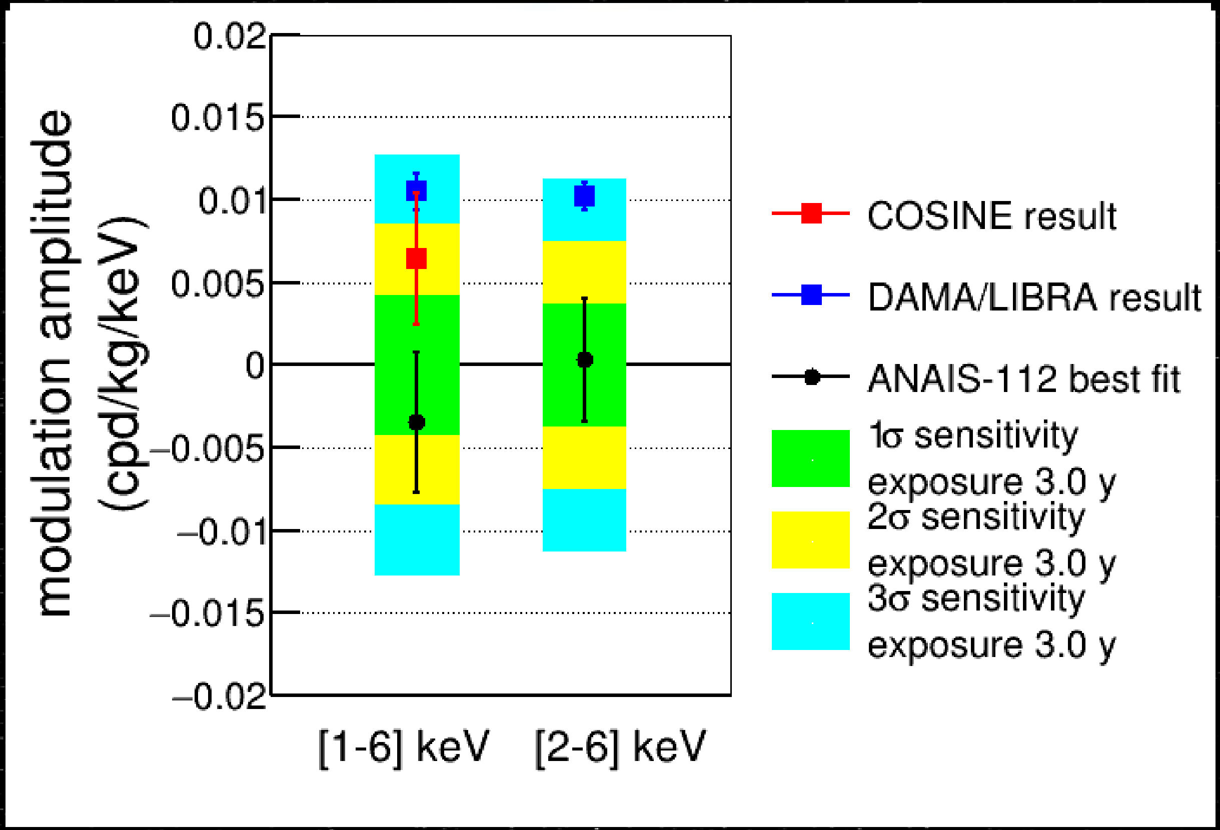


IN DATA-TAKING
~250 kg
Since Sept 2003 phase -1 / since Dec 2010 phase-2

Experiment	Laboratory	Technology	Target	Size	Status
DAMA/LIBRA	LNGS	Scintillator	NaI(Tl)	~250 kg	Running
ANAIS-112	LSC	Scintillator	NaI(Tl)	112.5 kg	Running
COSINE-100	Yangyang	Scintillator	NaI(Tl)	106 kg	Running
SABRE	LNGS,Stawell	Scintillator	NaI(Tl)	~50 kg	In preparation
PICOLON	Kamioka	Scintillator	NaI(Tl)	23.4 kg	In preparation
COSINUS	LNGS	Bolometer	NaI, NaI(Tl)	~1 kg	In preparation

Direct Detection of Dark Matter – APPEC Committee Report
arXiv:2104.07634

ANAIS-112 three year results – annual modulation analysis



- Best fits are incompatible with DAMA/LIBRA result at 3.3 and 2.6 σ in [1-6] and [2-6] keV energy regions
- Sensitivity is at 2.5 and 2.7 σ in [1-6] and [2-6] keV energy regions

New recent result from COSINE-100 experiment for three years

SUMMARY

Standard Model of the Particle Physics is under test in all the possible ways, looking for a new theory. Particle DM matches well in that scheme.

A lot of effort has been devoted to understand the nature of DM
Both, from theory and experiment/observation

The effort rewards on development of new detection techniques and pushing forward sensitivities to any rare process / unexpected interaction