High Energy Astroparticle Physics with gamma-rays and neutrinos: Focus on Fundamental Physics

DFA, Feb 2024

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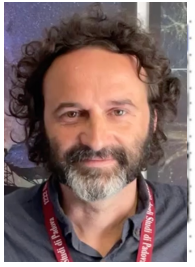

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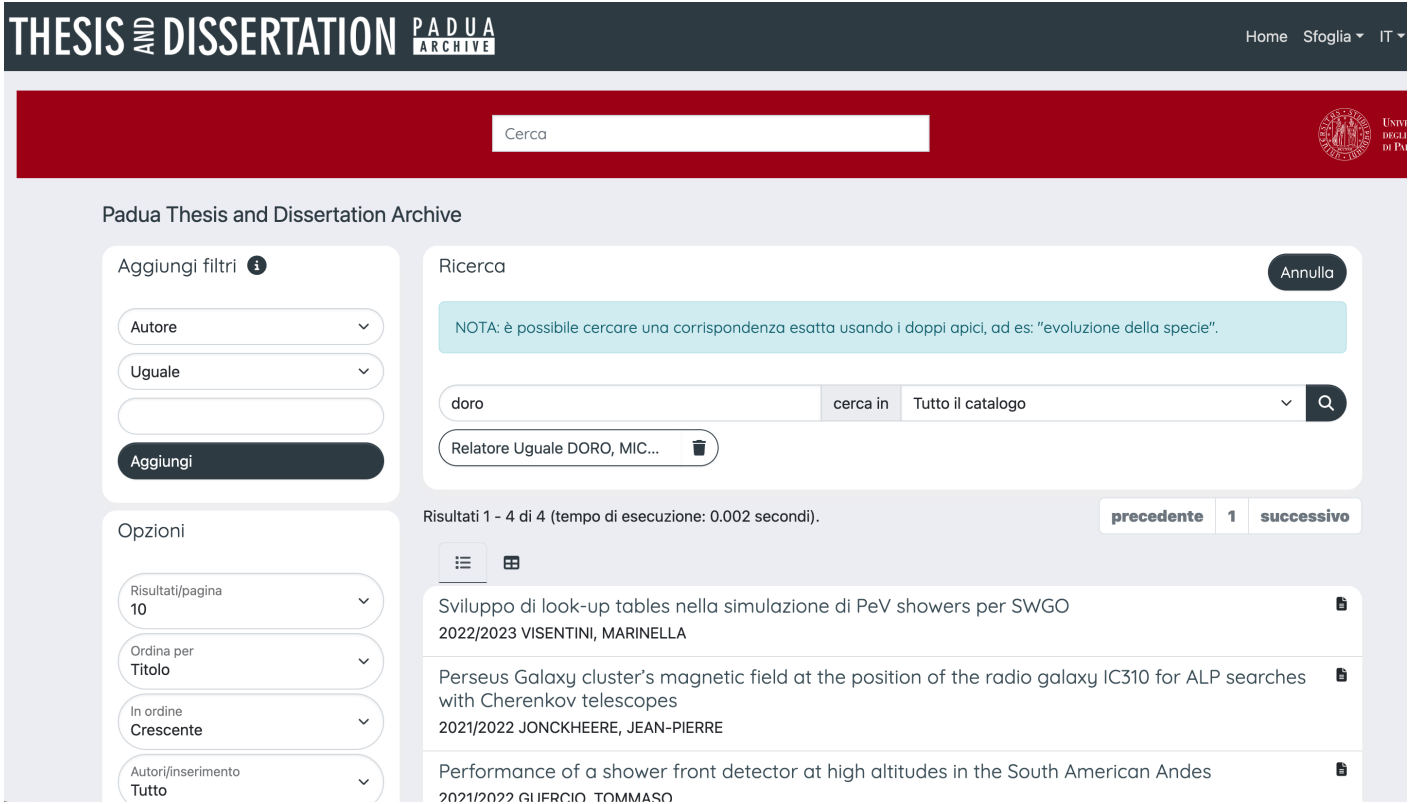
Catalog of theses UNIPD

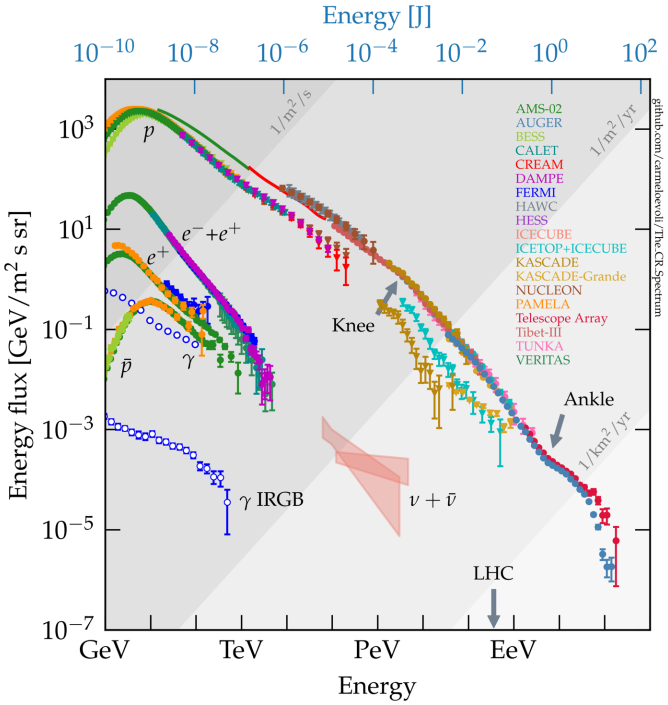


https://thesis.unipd.it/

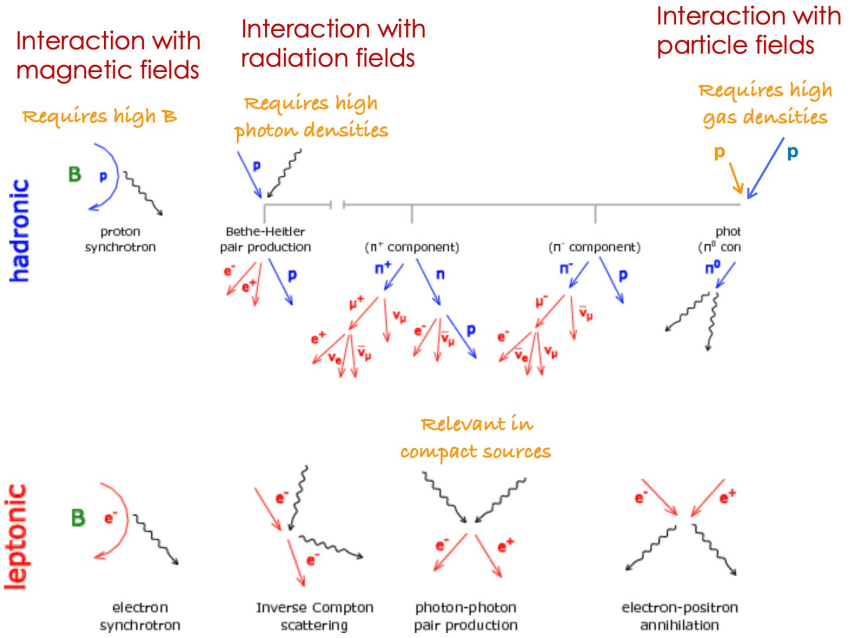
Search for'relatore' to check previous theses

Hereafter only some examples… ask us!

Gamma-rays and cosmic-rays



- Connected to cosmic-rays
- Particles hit the Earth! → Charged and Neutrinos

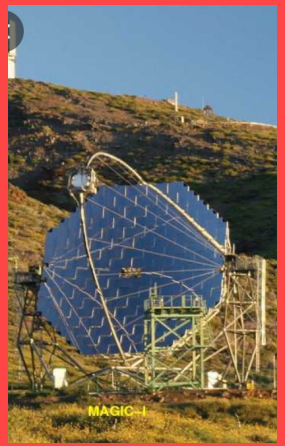


Gamma Ray (Cosmic-ray) detectors

MeV-GeV range
Satellite-borne detectors: FERMI

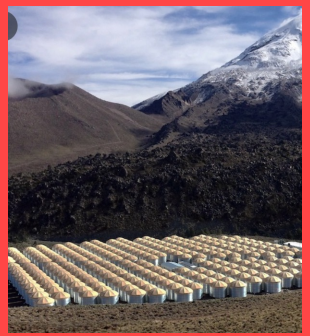
Rando/ Bottacini

TeV range
Ground-based detectors (light): MAGIC/CTA



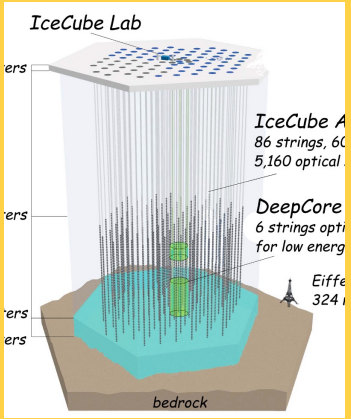
Doro/Prandini/Bernardini/Mariotti

TeV-PeV range
Compact Ground-based detectors (particles): SWGO



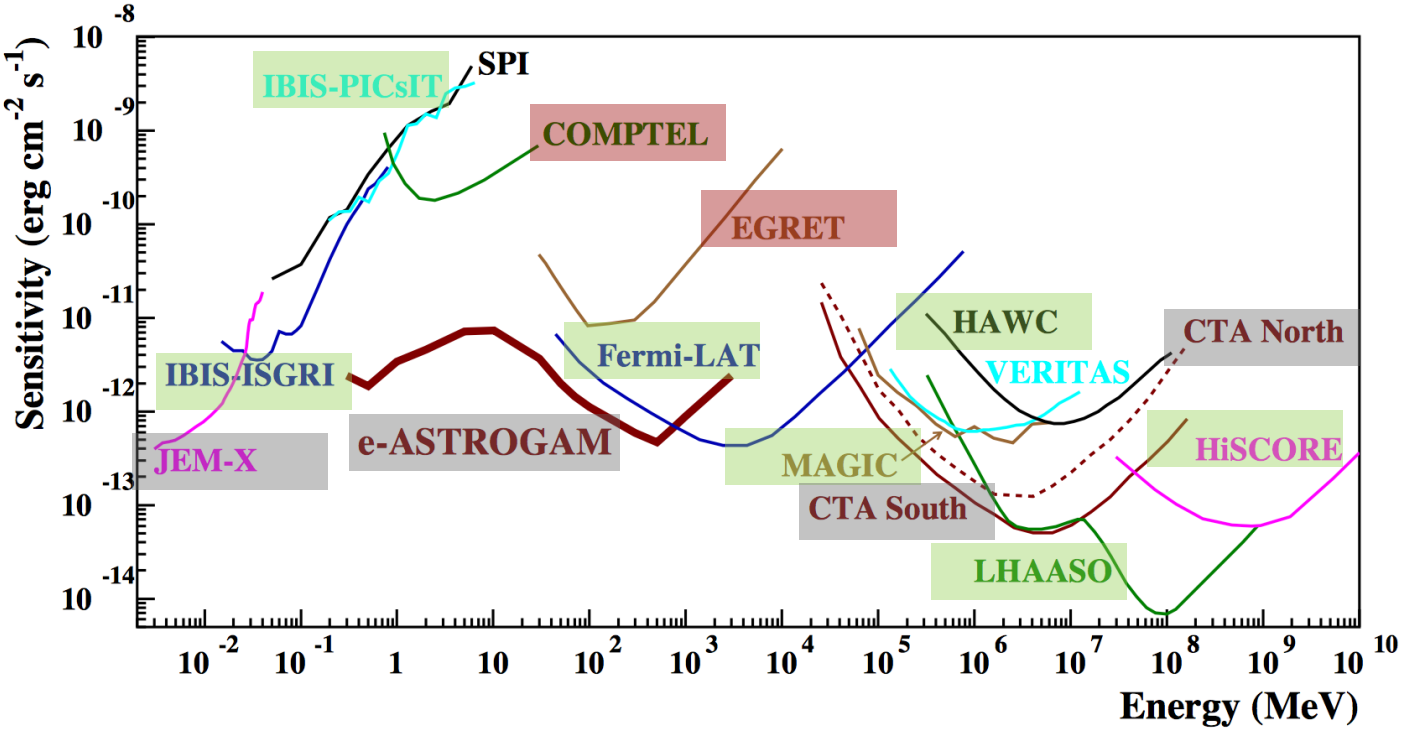
Doro/Dorigo

Neutrinos: IceCube



Bernardini

We need multiple instruments

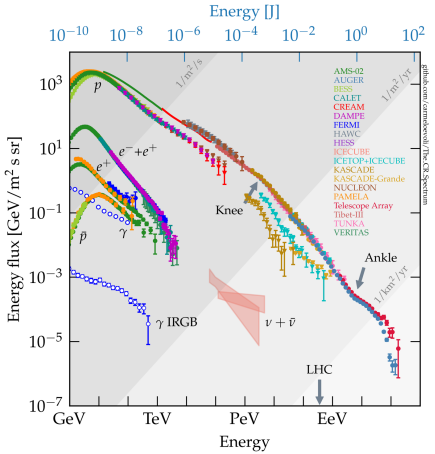


Past

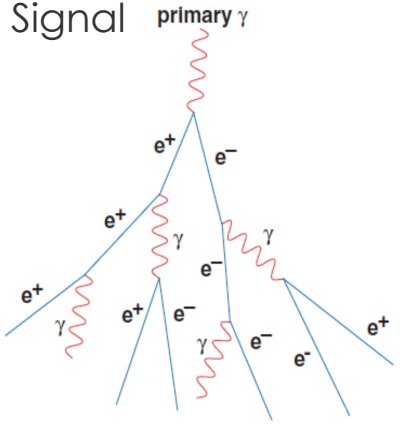
Present

Future

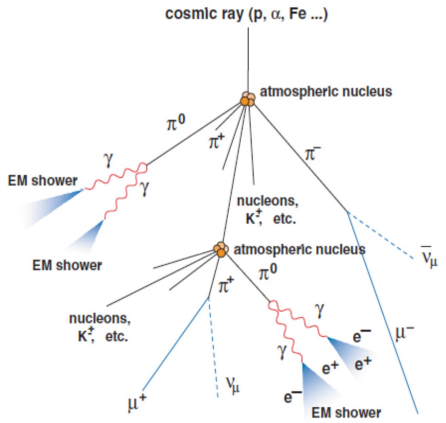
Atmospheric showers



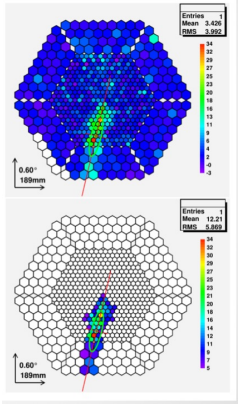
- Signal



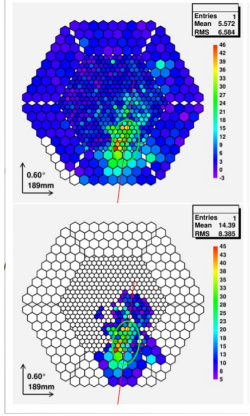
- (normally) **background 1000x more abudant**



Gamma (the good)



Hadron (the bad)

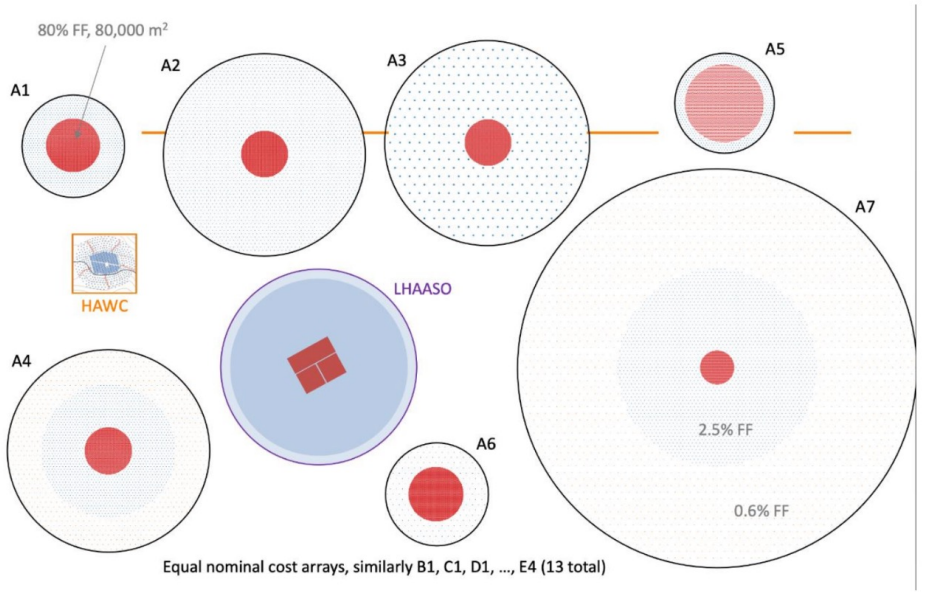


Thesis: neural network application to classification and regression [Mariotti, Prandini]

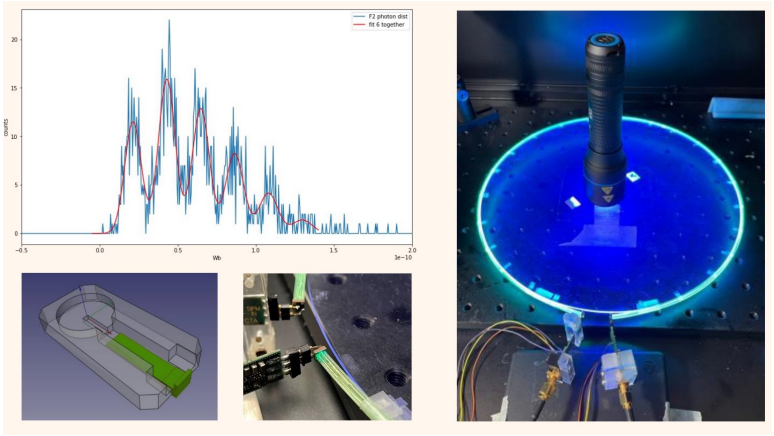
Shower Front Detectors

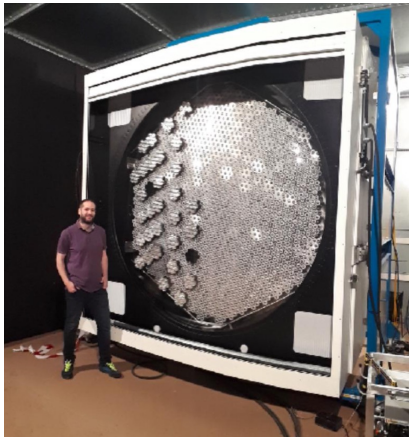
Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www.ast.leeds.ac.uk/~fs/showerimages.html

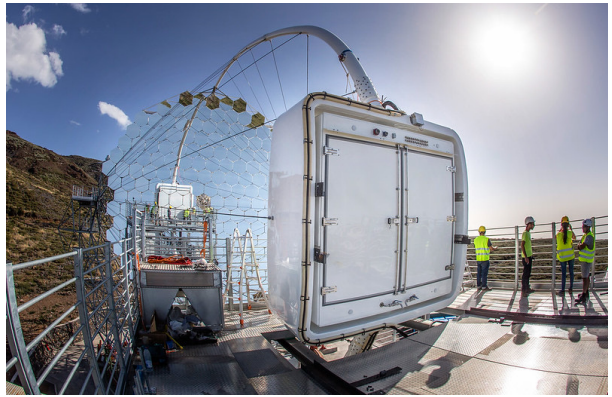
- Thesis [Doro, Dorigo] Array layout optimization via neural network



Photosensors and tech

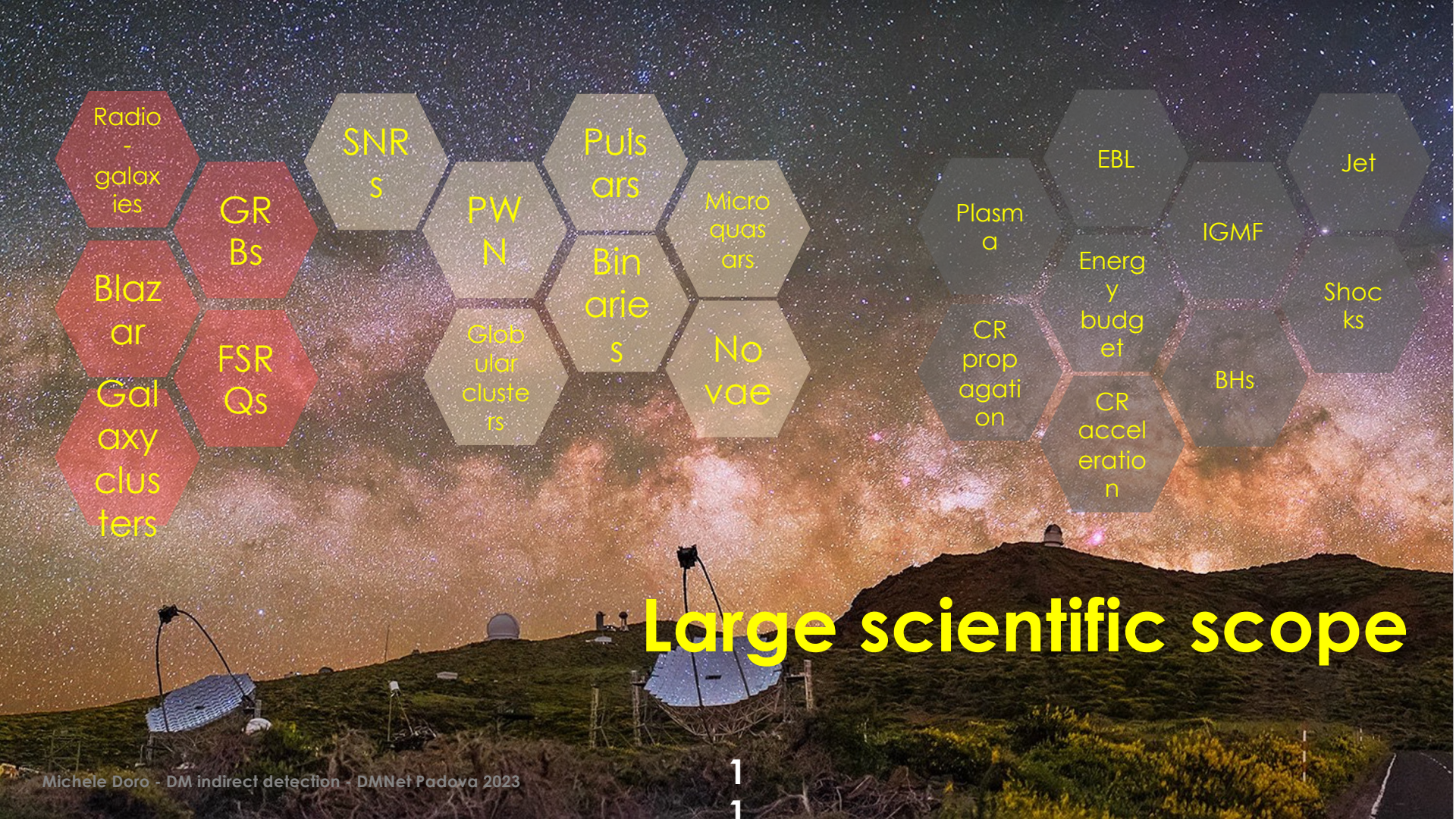




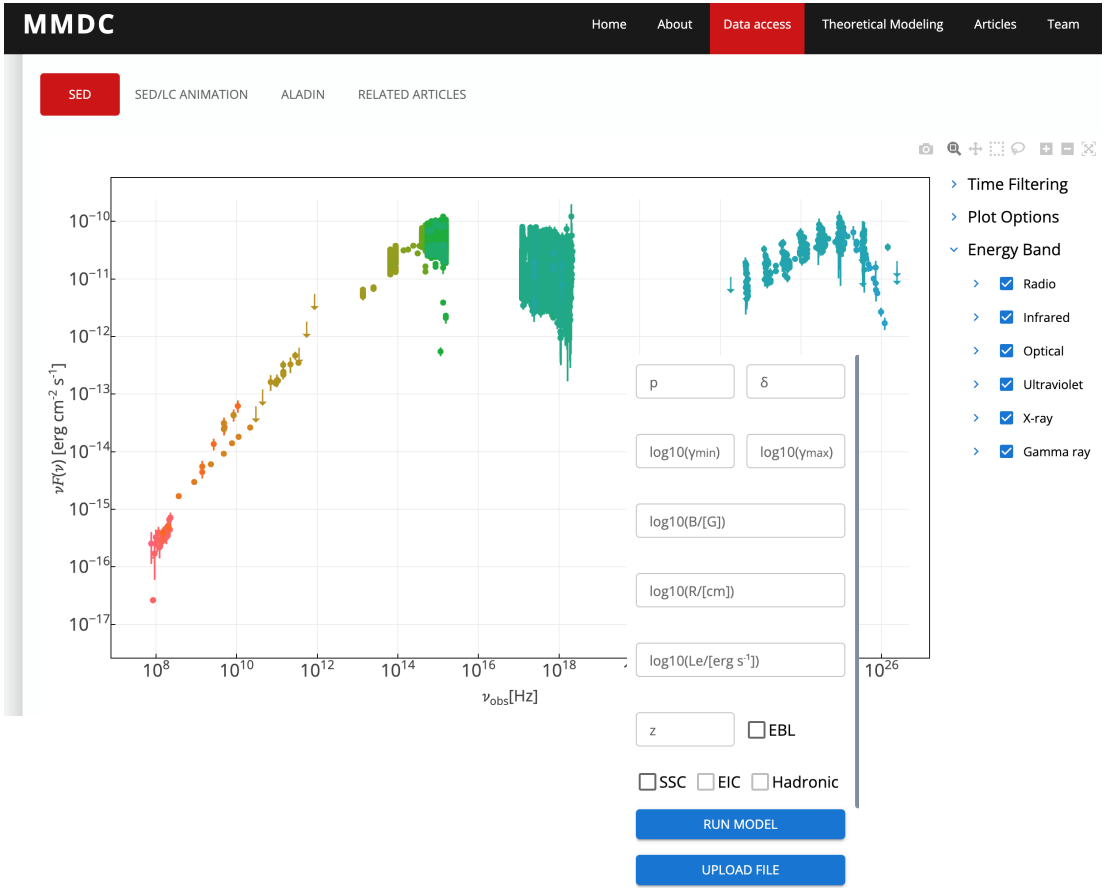


- Expertise in novel concept photosensors (light-traps scintillators) and new telescope cameras

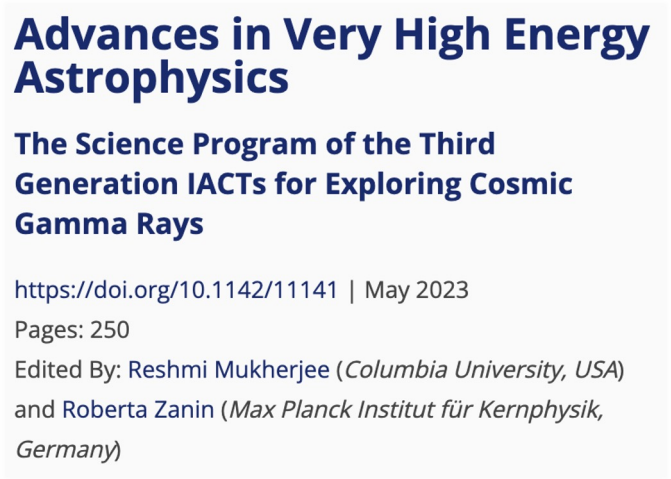
- Theses:
  - Lab measurements for photosensors [Mariotti, Rando]
  - New telescope camera concepts [Mariotti, Rando]


Radio-galaxies
GRBs
Blazar
FSRQs
Galaxy clusters
SNRs
PWN
Pulsars
Binaries
Globular clusters
Novae
Microquasars
Plasma
EBL
Jet
IGMF
Energy budget
Shocks
CR propagation
CR acceleration
BHs
Large scientific scope

Blazar modeling



- Tesis topics [Prandini, Bernardini, Doro,+]:
  - Modeling
  - Variability
  - Multi-w correlation
  - Observability prediction for future experiments: CTA/SWGO
  - Data handling

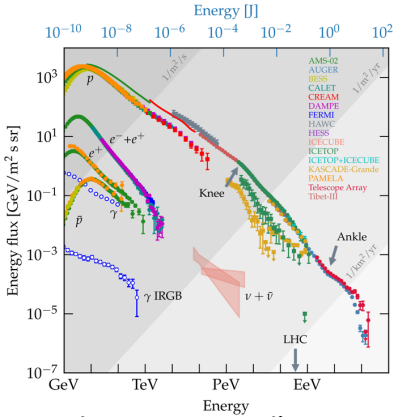


Fundamental physics topics (some pics)

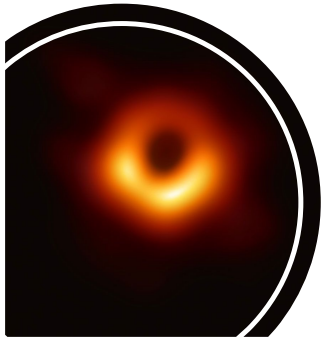
'Dark matter and fundamental physics with IACTs'
Doro, Sanchez-Conde, Hutten
https://arxiv.org/abs/2111.01198

[Doro, De Angelis, Bottacini]

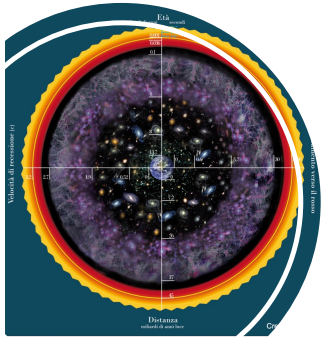
Why new physics in astroparticle?



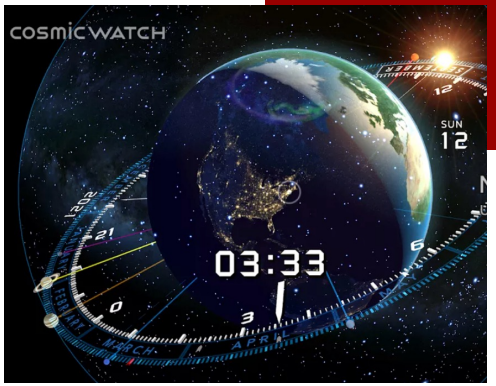
1/ A neverending powerful ENGINE



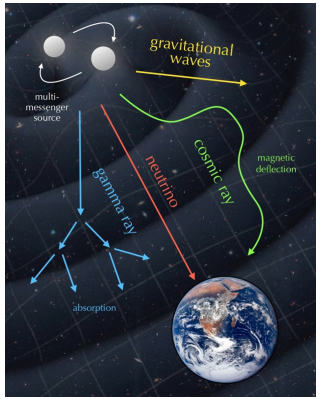
2/ particle acceleration through gravity infall

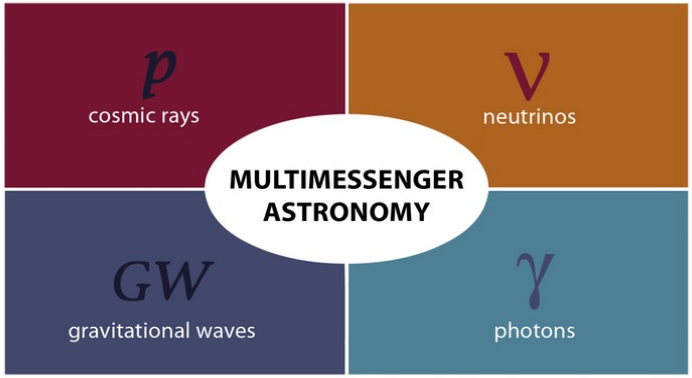


3/ huge volume and 'beam dump' (radiation, magnetic, particle fields)



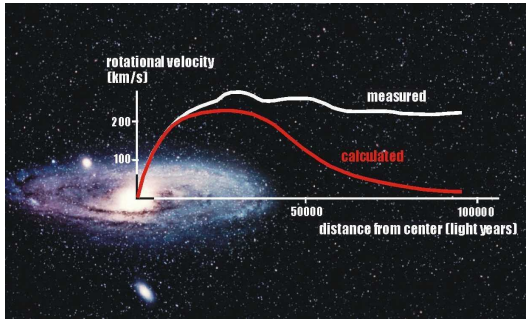
4/ trace events that happened at any time of the universe = any physics condition



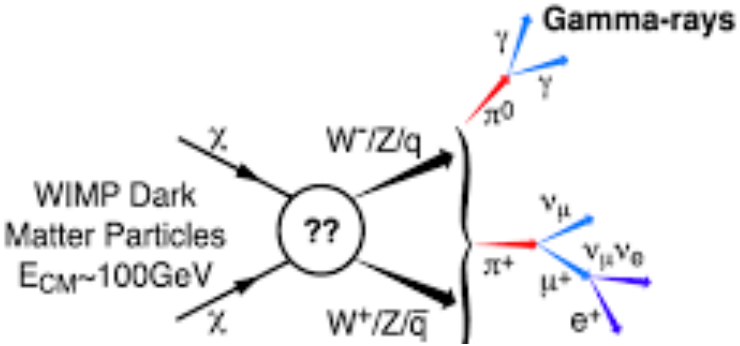


MULTIMESSENGER ASTROPARTICLE PHYSICS!

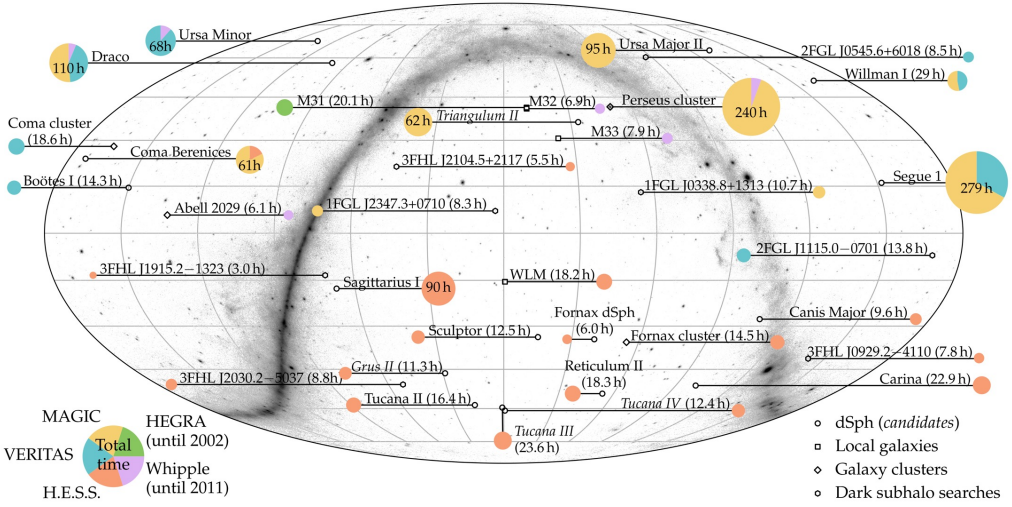
Case #1 Dark Matter



- Strong evidences for a new kind of particles 5x than SM particles



- Gamma-rays from DM annihilation/decay

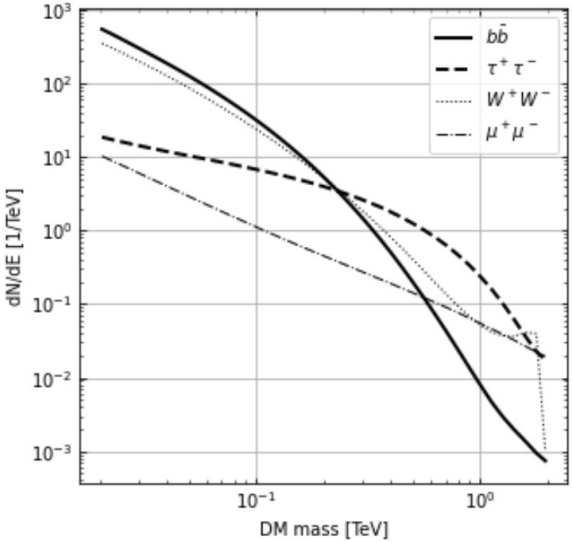


- **Targets:**
  - The Milky Way Center
  - The Milky Way satellite galaxies
  - Dark clumps of dark matter
  - Galaxy Clusters
  - ….

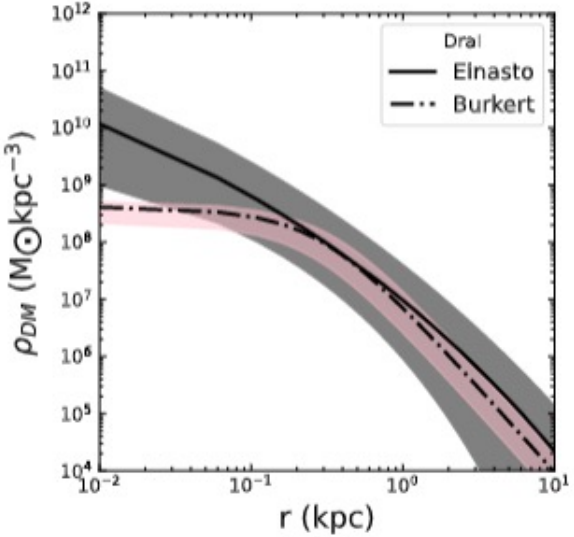
Analysis

- **Expected flux:**
  - Gamma-ray flux is due to DM microphysics + astrophysics

$$\frac{d\Phi_\gamma}{dE\,d\Omega} = \begin{cases} \dfrac{\langle\sigma v\rangle}{4k\pi\, m_{\rm DM}^2}\dfrac{dN_\gamma}{dE}\cdot\int_{\Delta\Omega}\int_{\rm l.o.s.}\rho_{\rm DM}^2(\ell,\Omega)\,d\ell\,d\Omega & \text{Annihilating DM} \\ \dfrac{1/\tau}{4\pi\, m_{\rm DM}}\dfrac{dN_\gamma}{dE}\cdot\int_{\Delta\Omega}\int_{\rm l.o.s.}\rho_{\rm DM}(\ell,\Omega)\,d\ell\,d\Omega & \text{Decaying DM} \end{cases}$$

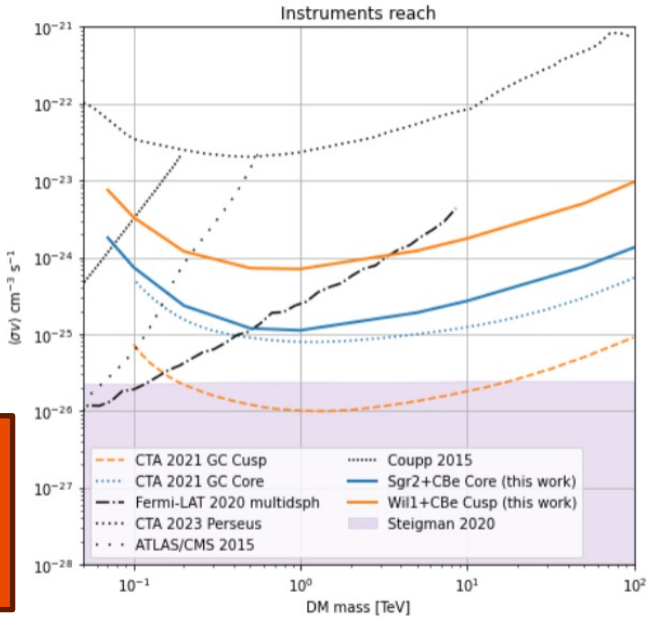


- **1st Step: MODEL THE DM EMISSION**
  - Physics programs (micromegas, pythia, etc)
- **2nd Step: SELECT TARGET AND MODEL DM DENSITY**
  - Match stellar motions



Example of current search #1: WIMP DM

- **3nd Step: TAKE INSTRUMENT DATA**
  - With MAGIC: actual data
  - With CTA: simulated data

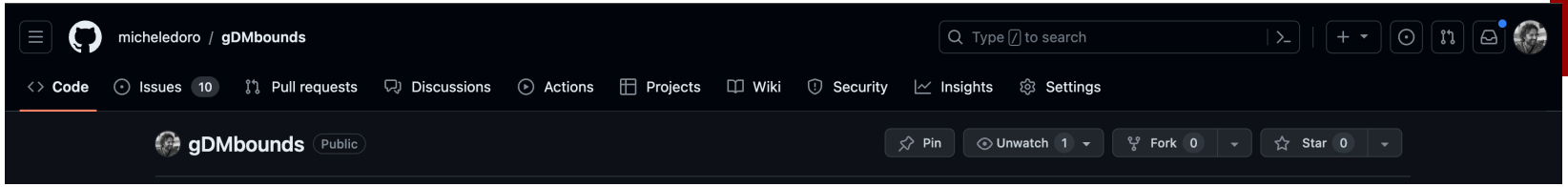


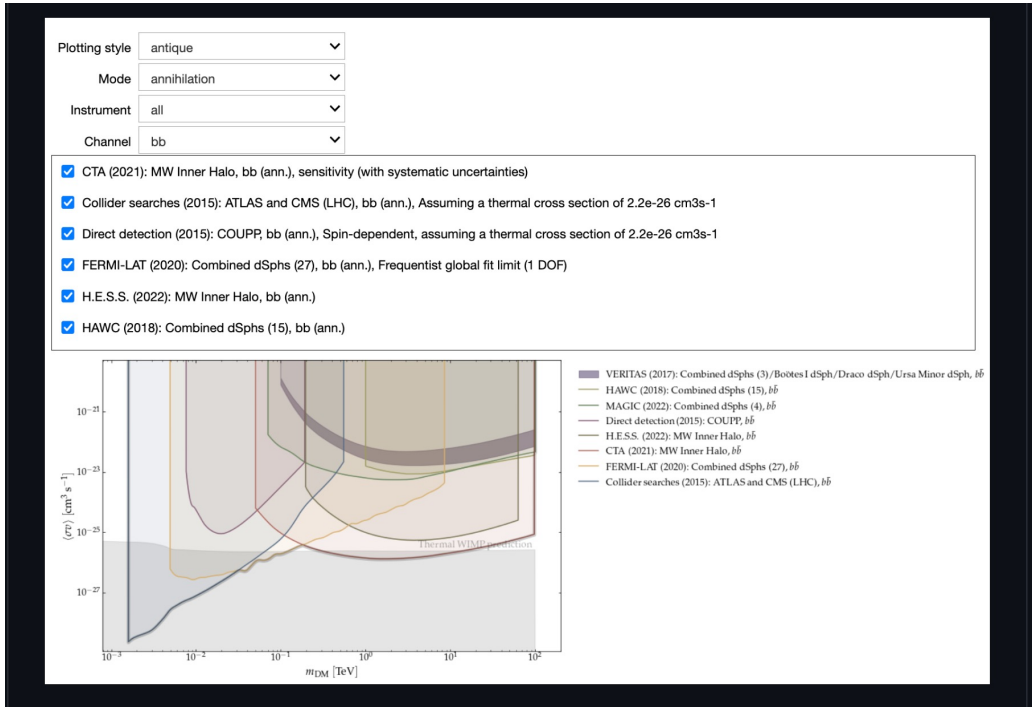
- **4nd Step ANALYSIS**
  - If detection → go to Stockholm!
  - If non detection → constraints on DM properties (this model is ruled out)

Available now

- *Theses (LM) DM phenomenology, instrument data reco pipelines, data analysis*

gDMbounds: data portal

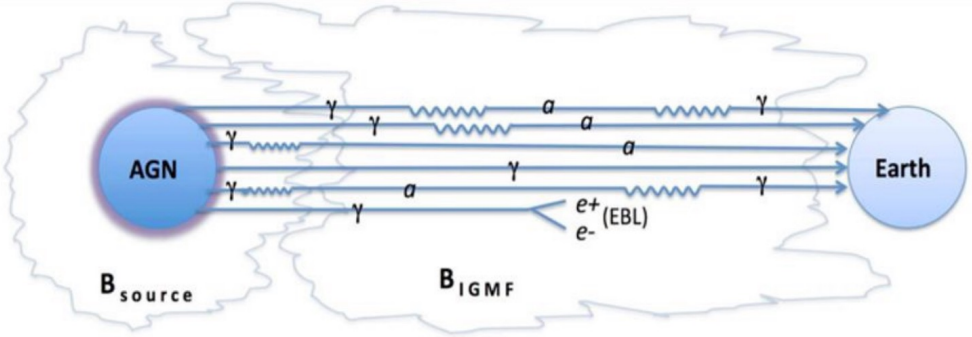


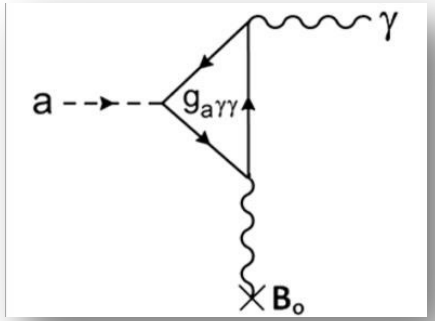


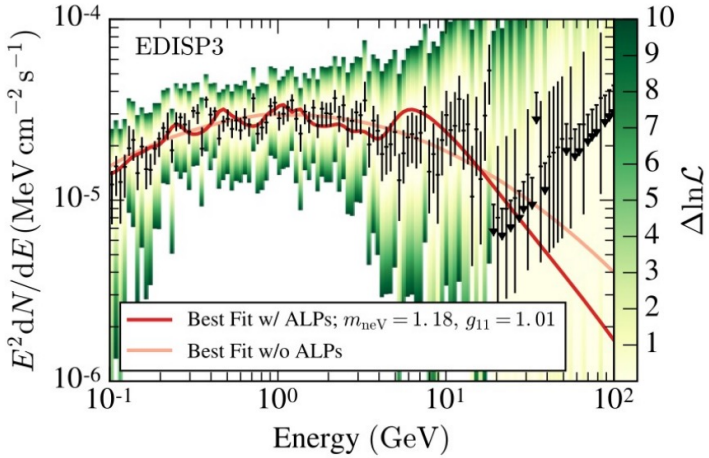
- https://github.com/micheledoro/gDMbounds/ gather experimental data and work on them

- Thesis LT/LM [Doro]
  - Gather new data, cast data among experiments, discuss results,…

Case #2: ALPs



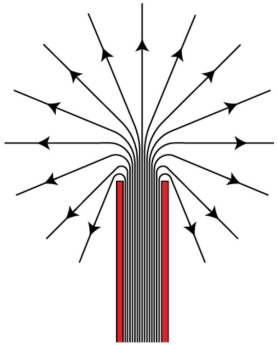




- Hypothesis:
  - Axion-like particle type DM (<<eV) oscillates to photons in external magnetic fields (<<pb)
  - Strong magnetic fields in the Universe+long-distance makes effect measurable

THESIS LM/LT [Doro] As before: signal model, data analysis, results. →instruments data pipelines, data analysis

Case #3: Magnetic Monopoles

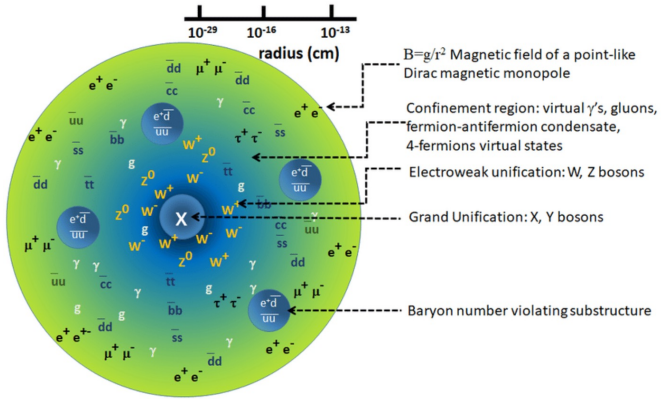


$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 J + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$



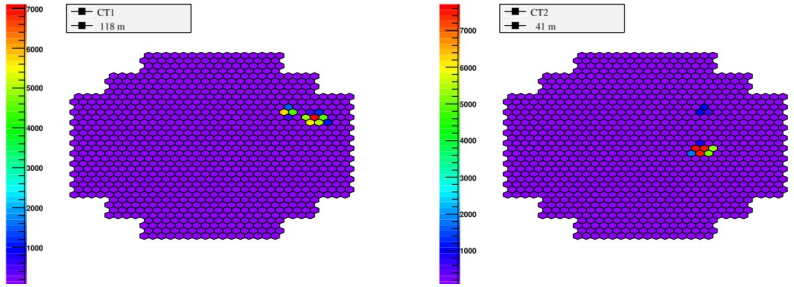
- Magnetic Monopoles make Maxwell's equation symmetric → :-)

The Equation of Motion of the Monopoles

$$m\frac{d}{dt}(\gamma v) = gB - \left(f_{\mathrm{p}} + mH\gamma\right)v$$

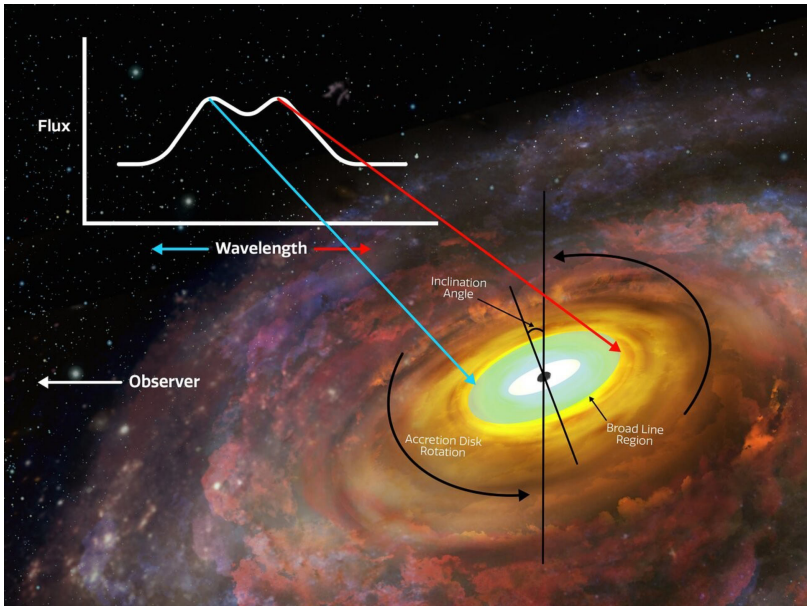
Acceleration in Intergalactic Magnetic Fields

- MMs produce huge atmospheric showers in the atmosphere!



Rewriting bounds from experiments

Physics of Supermassive Black Holes



Recently, frame-dragging (from General Relativity) has become measurable with current space missions allowing to determine properties of supermassive black holes (e.g. **mass**, **spin**, **accretion disk**, **particle physics**).

Such properties can shed light onto the formation of jets, the feedback in galaxies, accretion history, particle physics, and much more.

[Bottacini]

Curious?

- Theses proposed depends on opportunity at that time and student wishes.
  - fenomenology/data analysis/simulation
  - hardware/software
  - Padova/European partner

- Offer can be declinated to all Physics and Astronomy cicles
  - Keywork 'gamma-ray astronomy' on theses webpage https://tesi.dfa.unipd.it/

- Better to contact one of us to discuss options!

You can join our weekly meeting Thu at 10 room 313 to get to know our activities

mailto: heap@lists.pd.infn.it

Contacts

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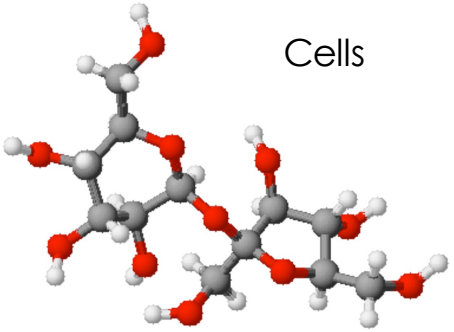
- **Group**:
  - Instrumentation (photosensors): Mosè Mariotti & Riccardo Rando
  - Black holes and relativistic jets in AGN: Elisa Bernardini & Elisa Prandini
  - Radiative mechanisms in galactic objects: Luca Zampieri
  - High energy neutrino astrophysics: Elisa Bernardini
  - Fundamental (astroparticle) physics: Michele Doro & Alessandro de Angelis
  - High energy surveys: Eugenio Bottacini & Riccardo Rando
  - Intensity Interferometry: G. Naletto & L. Zampieri

Energy conversion efficiency

$$\eta = \frac{\Delta E}{\Delta m c^2}$$

Credit: Gabriele Ghisellini

$$\eta = \frac{mgh}{mc^2} = \frac{980 \times 10^4 \,(h/100\ m)}{9 \times 10^{20}\ erg} \sim 10^{-14}$$

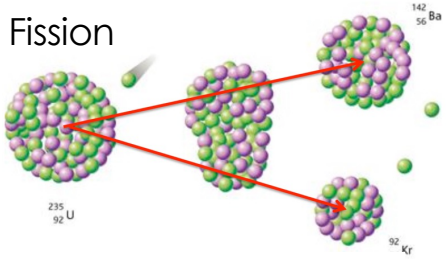


Cells

Sugar saccharose $C_{12}H_{22}O_{11}$

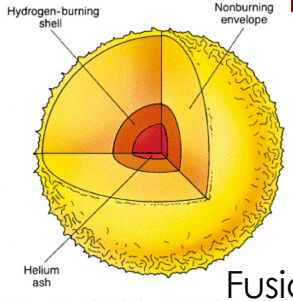
$$\eta = \frac{E}{mc^2} = \frac{1.6 \times 10^{11} erg}{9 \times 10^{20}\ erg} = 1.8 \times 10^{-10}$$

$$\eta = \frac{mv^2}{2\,mc^2} = \frac{(v/c)^2}{2} = 4 \times 10^{-15}$$



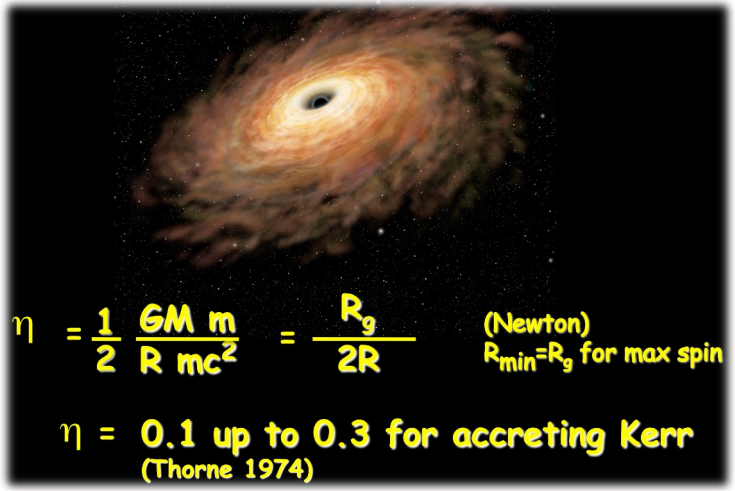
Fission

$$\eta = \frac{E}{mc^2} = \frac{0.2 \times 10^9 eV}{235 \times 9.4 \times 10^8\ eV} \sim 9 \times 10^{-4}$$



Fusion

$$\eta = 0.008 \times 0.1 \sim 8 \times 10^{-4}$$



$$\eta = \frac{1}{2}\frac{GM\,m}{R\,mc^2} = \frac{R_g}{2R}$$

(Newton)
$R_{min}=R_g$ for max spin

η = 0.1 up to 0.3 for accreting Kerr
(Thorne 1974)