



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

DFA, Feb 2024

Speaker: **MICHELE DORO** michele.doro@unipd.it int 5909

Group: High Energy Astroparticle Physics t.ly/S30BX

Group mail: heap@lists.pd.infn.it

High Energy Astroparticle Group

2

Alessandro de Angelis
INFN dir. of
Prof. Ordinario



Mose' Mariotti
Prof. Ordinario



Elisa Bernardini
Prof. Associato



Denis Bastieri
Prof. Associato



Michele Doro
Prof. Associato



Riccardo Rando
Prof. Associato



Giampiero Naletto
Prof. Associato



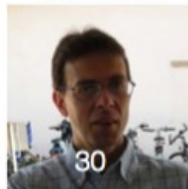
Elisa Prandini
RTDB



Tommaso Dorigo
(INFN)



(INAF)
Luca Zampieri
Researcher



Cornelia Arcaro
(INFN)



Davide Miceli
(INFN)



Ivana Batkovic
(postdoc)



Arshia Ruina
(postdoc)



Sarah Mancina
(postdoc)



Ilaria Viale
(postdoc)

Jorge Otero Santos
(soon, postdoc)



PHDs!

Silvestri	Giuseppe
Recabarren	Luis

mailto: heap@lists.pd.infn.it

Catalog of theses UNIPD

3

The screenshot shows the 'Padua Thesis and Dissertation Archive' search page. At the top, there is a dark header with the site name and navigation links. Below this is a red search bar with a search icon and a 'Cerca' button. The main content area is white and contains a search filter sidebar on the left, a search input field with a search button, and a list of search results. The search filter sidebar includes options for 'Aggiungi filtri', 'Autore', 'Uguale', and 'Opzioni'. The search input field contains the text 'Relatore Uguale DORO, MIC...' and a search button. The search results list shows three entries, each with a title, author, and year.

THESIS AND DISSERTATION ARCHIVE PADUA ARCHIVE Home Sfoglia IT

Cerca

Padua Thesis and Dissertation Archive

Aggiungi filtri

Autore

Uguale

Aggiungi

Ricerca

NOTA: è possibile cercare una corrispondenza esatta usando i doppi apici, ad es: "evoluzione della specie".

doro cerca in Tutto il catalogo

Relatore Uguale DORO, MIC...

Risultati 1 - 4 di 4 (tempo di esecuzione: 0.002 secondi).

precedente 1 successivo

Sviluppo di look-up tables nella simulazione di PeV showers per SWGO
2022/2023 VISENTINI, MARINELLA

Perseus Galaxy cluster's magnetic field at the position of the radio galaxy IC310 for ALP searches with Cherenkov telescopes
2021/2022 JONCKHEERE, JEAN-PIERRE

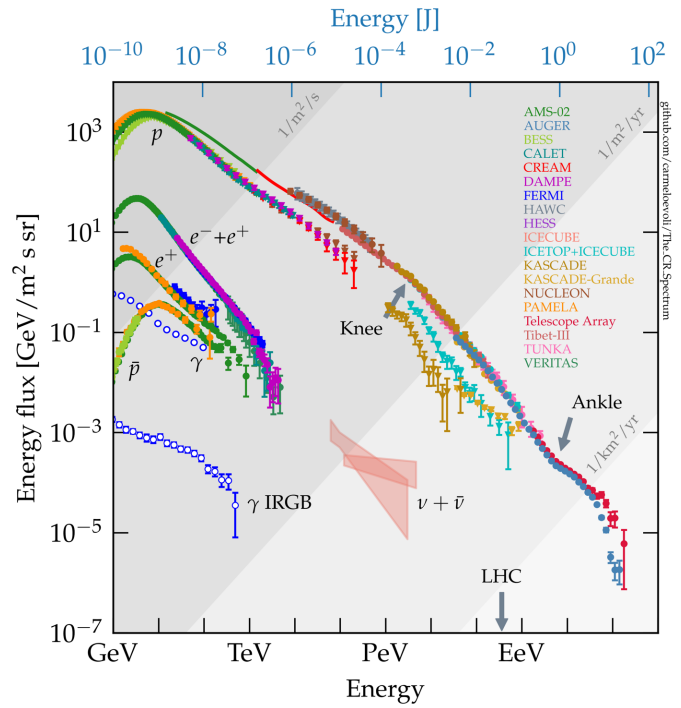
Performance of a shower front detector at high altitudes in the South American Andes
2021/2022 GUERCIO, TOMMASO

<https://thesis.unipd.it/>

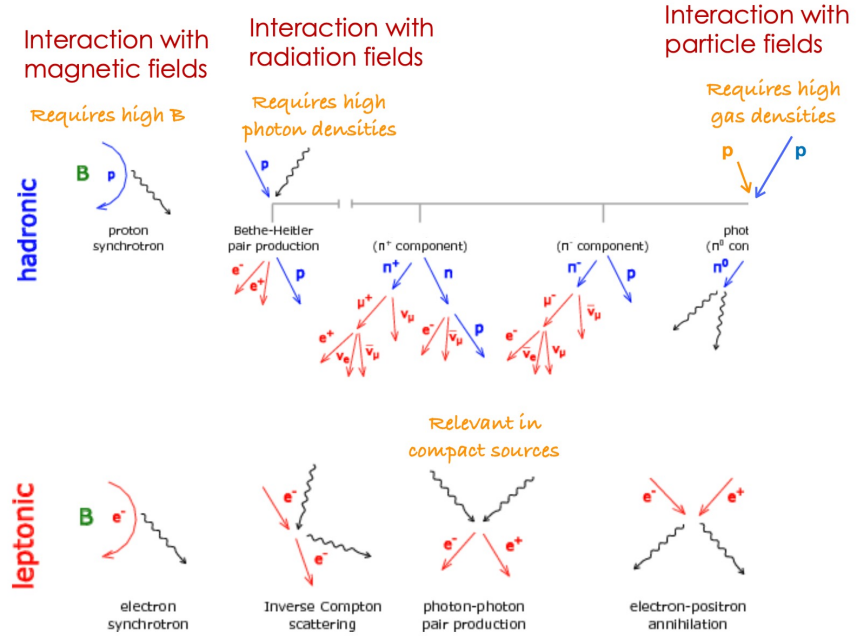
Search for 'relatore' to check previous theses

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



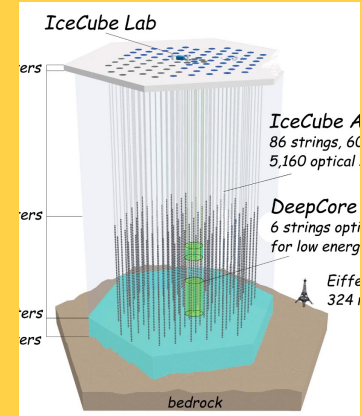
Doro/Prand
ini/Bernardi
ni/Mariotti

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



Doro/Dorigo

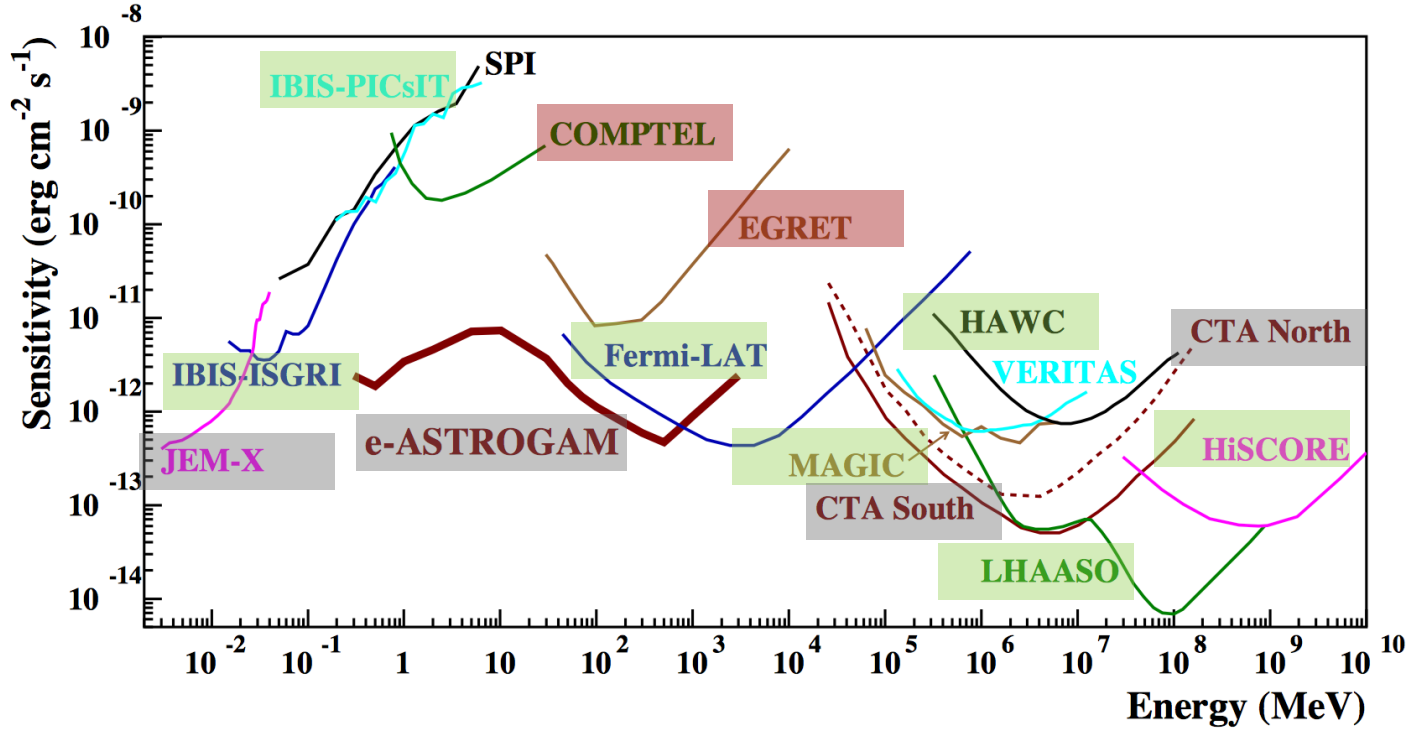
Neutrinos: IceCube



Bernardini

We need multiple instruments

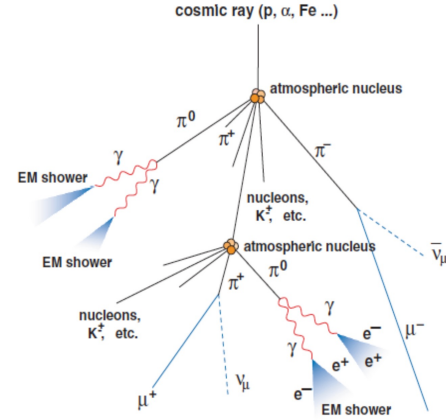
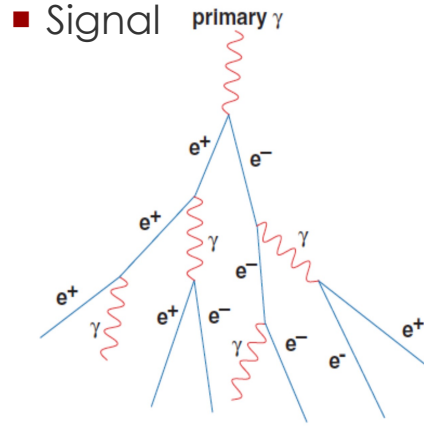
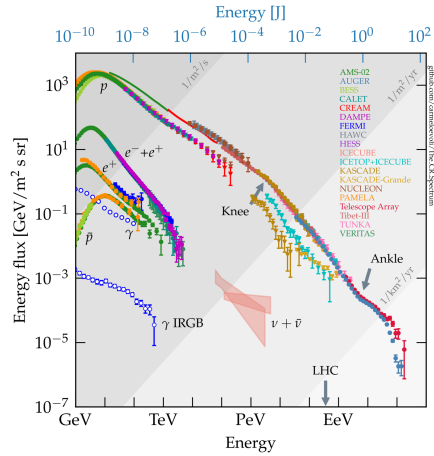
6



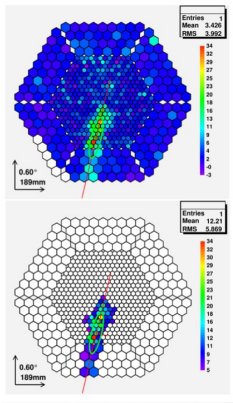
Atmospheric showers



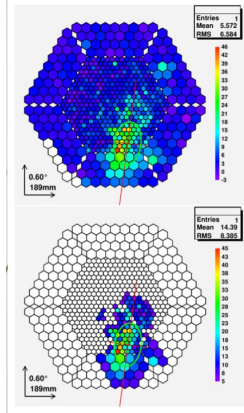
- (normally) **background**
1000x more abundant



Gamma (the good)

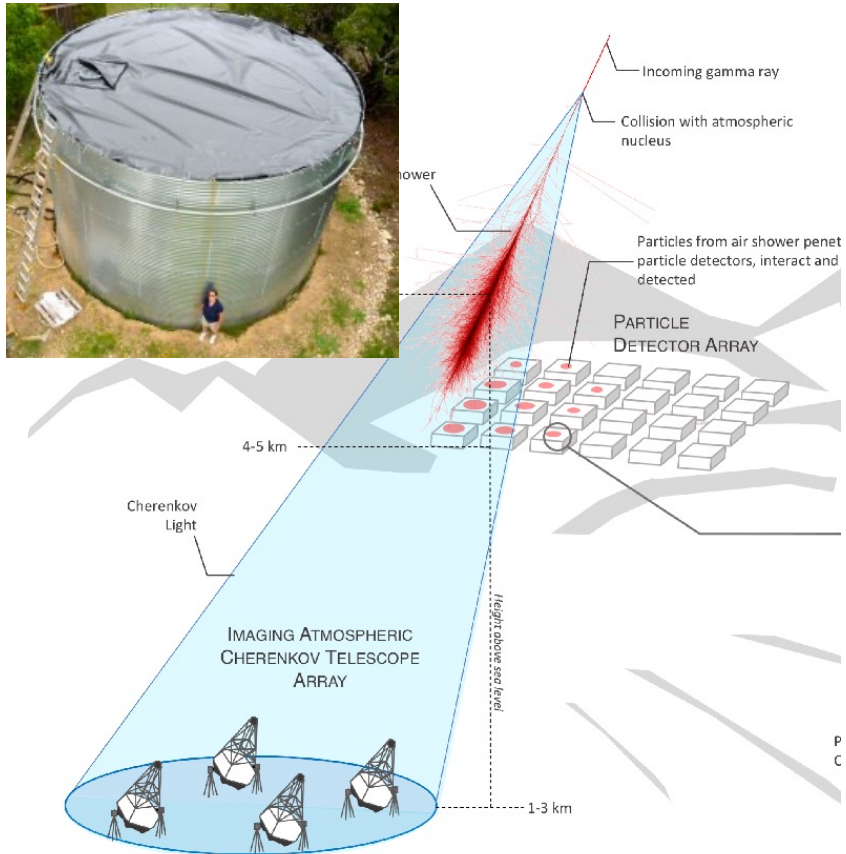


Hadron (the bad)

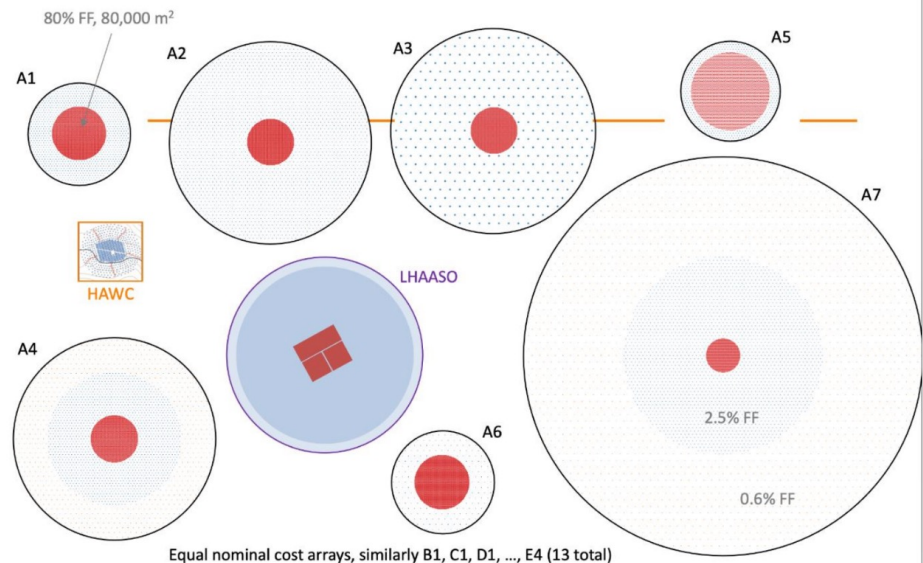


Thesis: neural network application to classification and regression [Mariotti, Prandini]

Shower Front Detectors



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

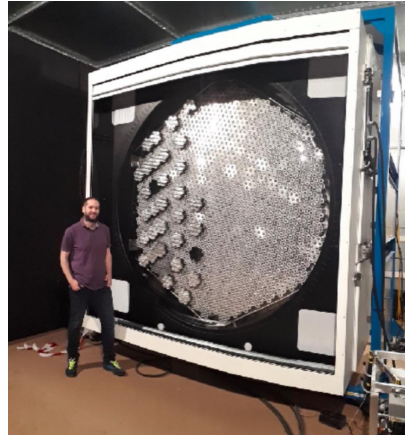
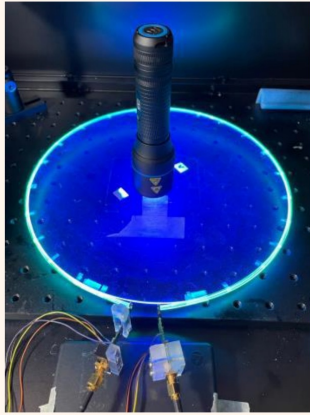
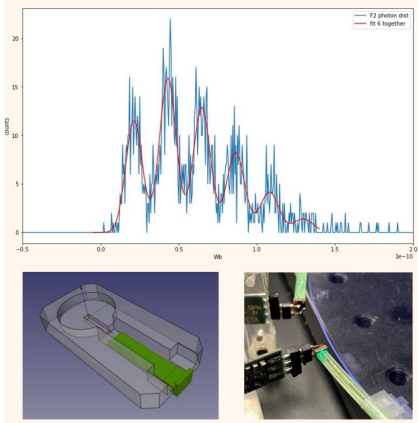


Equal nominal cost arrays, similarly B1, C1, D1, ..., E4 (13 total)

Shower image, 100 GeV γ -ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, <https://www.zcu.ch/cn.acsv.de/~knapp/fs/showcrimaacs.html>

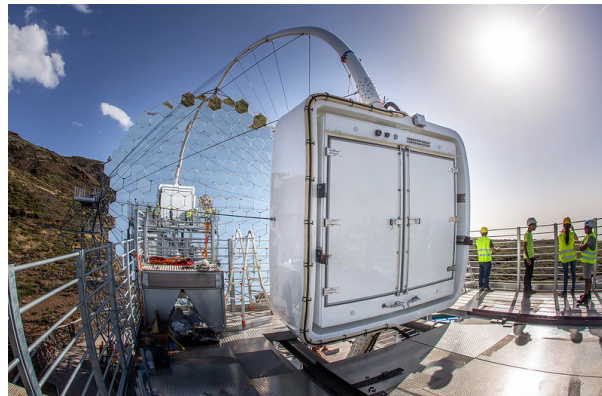
Photosensors and tech

10



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

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

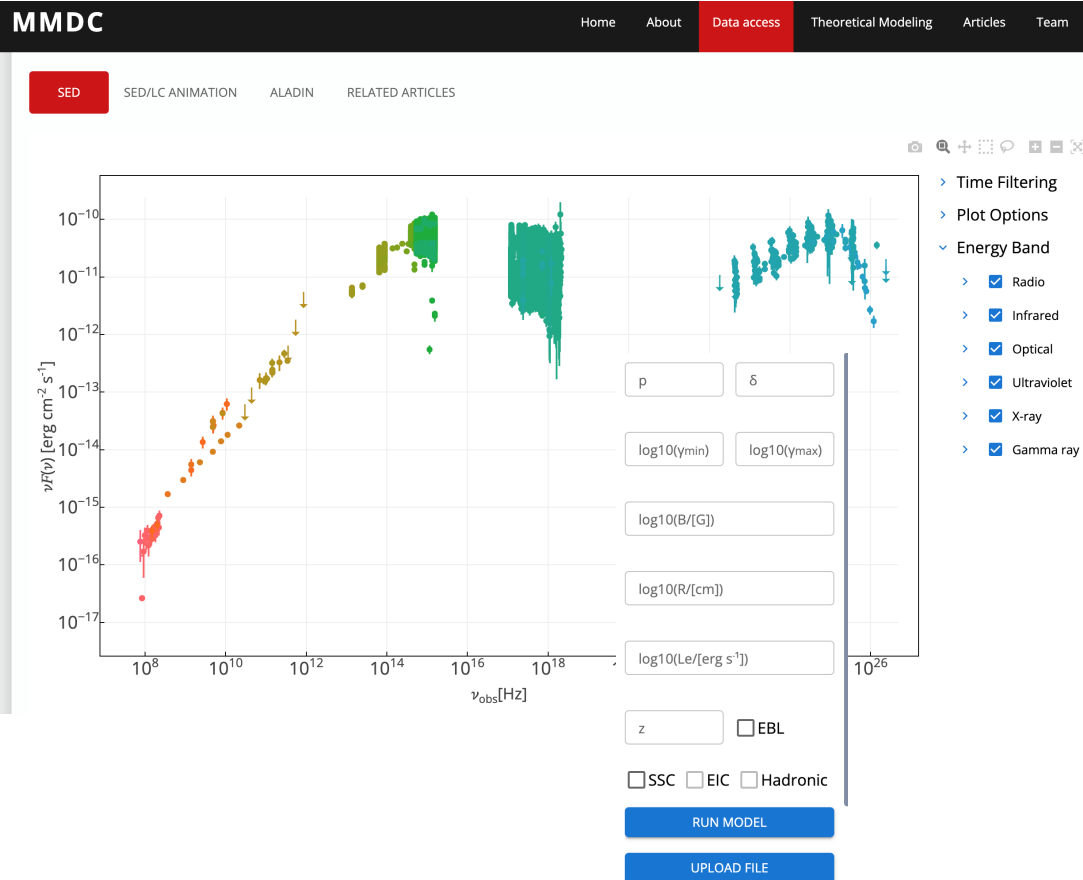




Large scientific scope

Blazar modeling

12



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

Advances in Very High Energy Astrophysics

The Science Program of the Third Generation IACTs for Exploring Cosmic Gamma Rays

<https://doi.org/10.1142/11141> | May 2023

Pages: 250

Edited By: Reshmi Mukherjee (*Columbia University, USA*)
and Roberta Zanin (*Max Planck Institut für Kernphysik, Germany*)

'Dark matter and fundamental physics with IACTs'

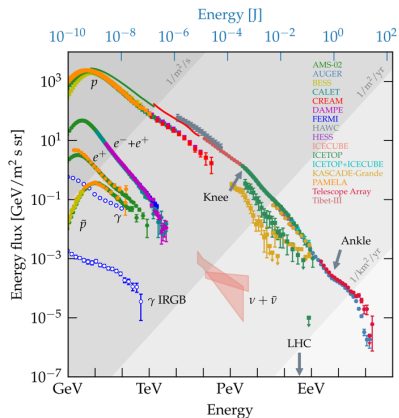
Doro, Sanchez-Conde, Hutten

<https://arxiv.org/abs/2111.01198>

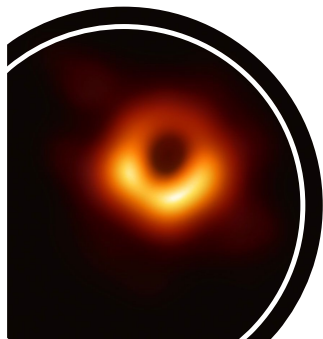
Fundamental physics topics (some pics)

[Doro, De Angelis, Bottacini]

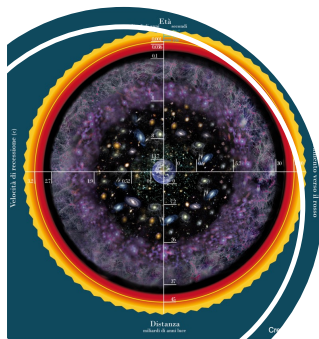
Why new physics in astroparticle?



1/ A neverending powerful ENGINE



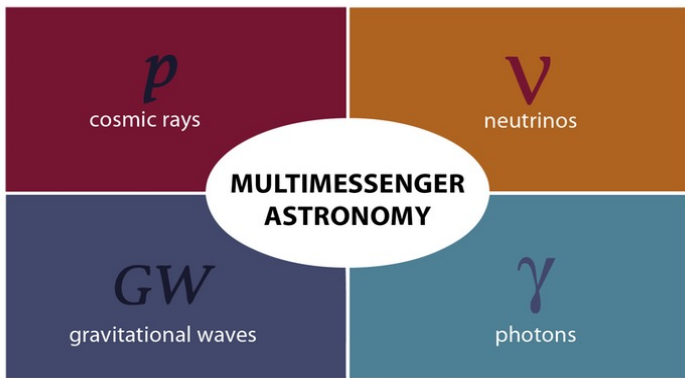
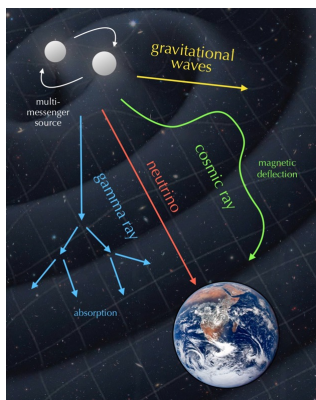
2/ particle acceleration through gravity infall



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



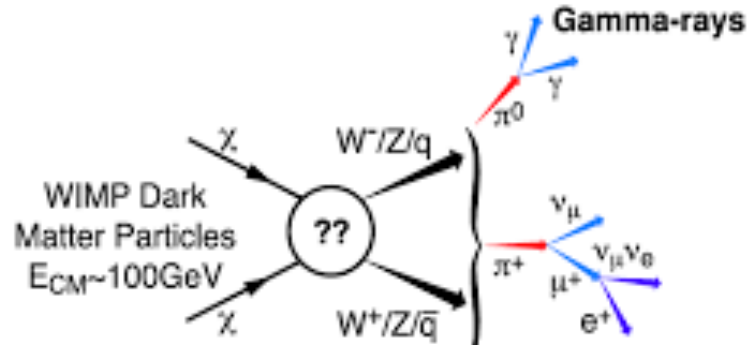
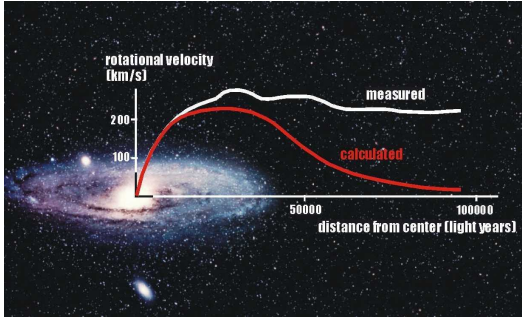
4/ trace events that happened at any time of the universe = any physics condition



**MULTIMESSENGER
ASTROPARTICLE PHYSICS!**

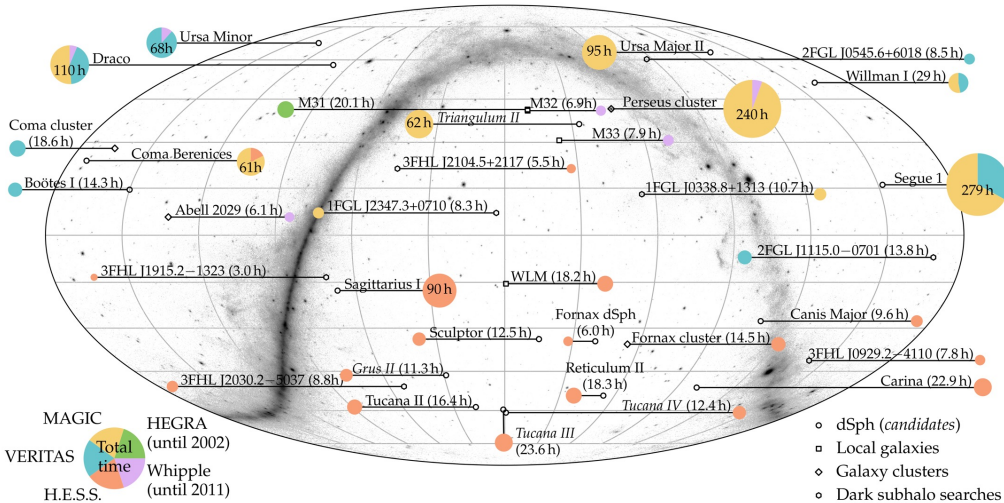


Case #1 Dark Matter



- Gamma-rays from DM annihilation/decay

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



Targets:

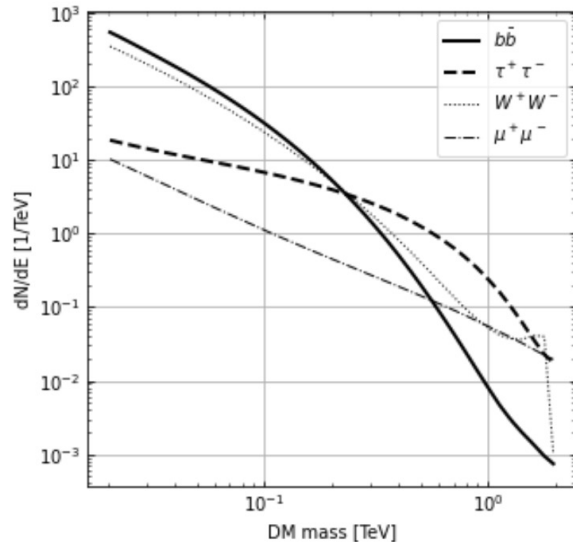
- The Milky Way Center
- The Milky Way satellite galaxies
- Dark clumps of dark matter
- Galaxy Clusters
-

Analysis

Expected flux:

- Gamma-ray flux is due to DM microphysics + astrophysics

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

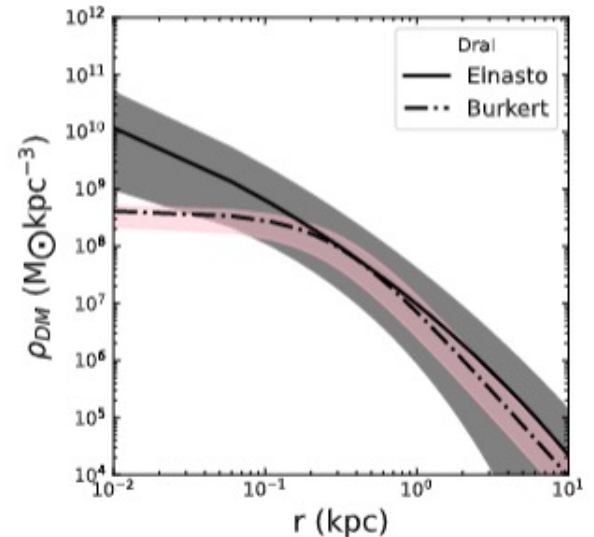


1st Step: MODEL THE DM EMISSION

- Physics programs (micromegas, pythia, etc)

2nd Step: SELECT TARGET AND MODEL DM DENSITY

- Match stellar motions



Example of current search #1: WIMP DM

17



■ 4th Step ANALYSIS

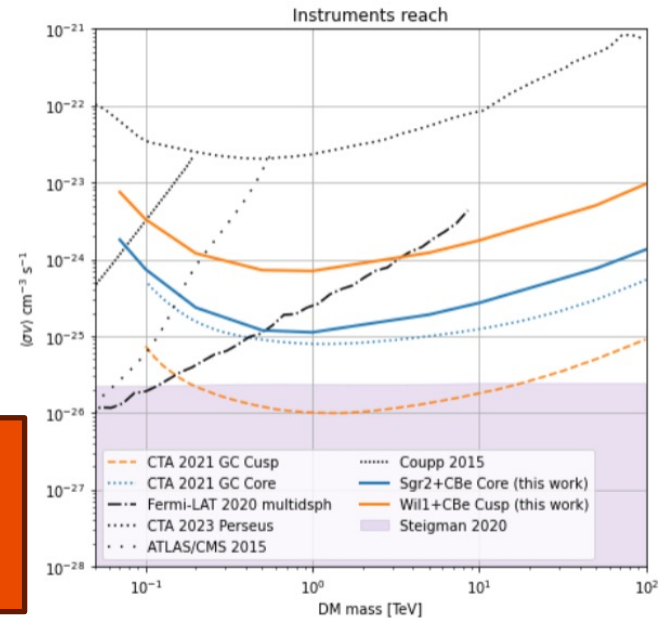
- If detection → go to Stockholm!
- If non detection → constraints on DM properties (this model is ruled out)

Available now

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

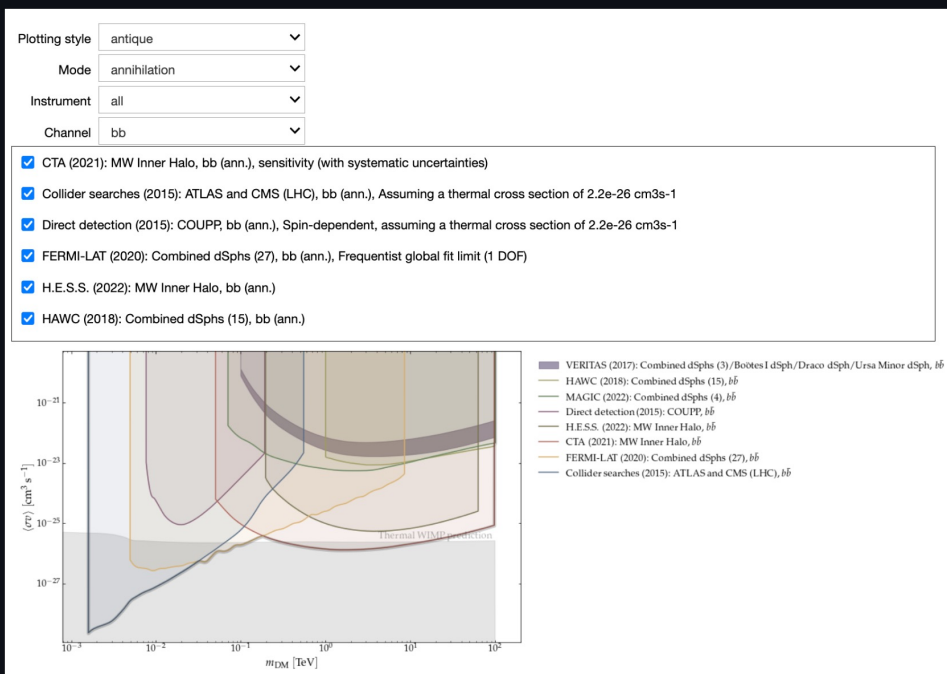
■ 3rd Step: TAKE INSTRUMENT DATA

- With MAGIC: actual data
- With CTA: simulated data



gDMbounds: data portal

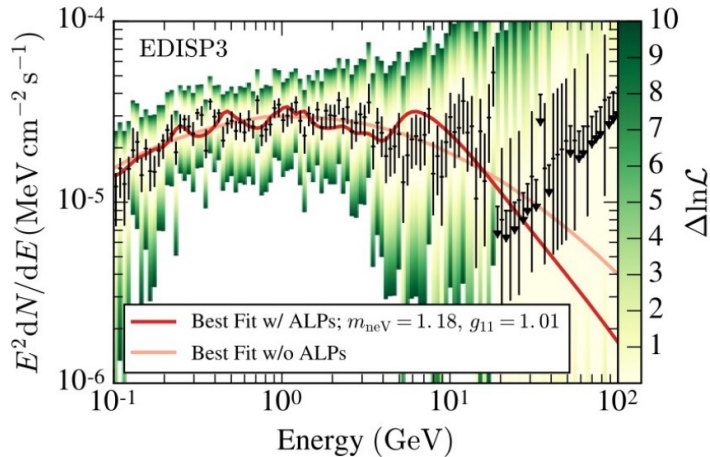
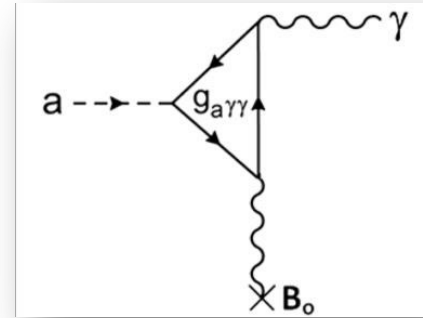
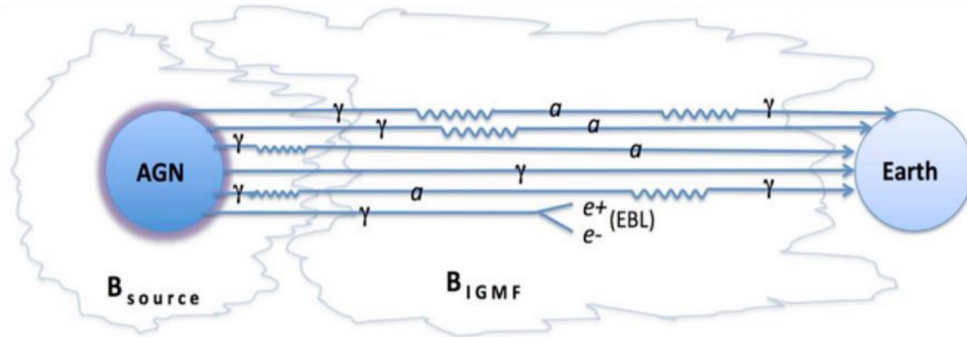
18



- <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

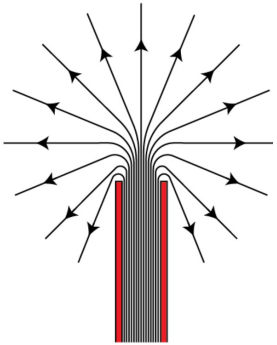


■ Hypothesis:

- Axion-like particle type DM ($\ll eV$) oscillates to photons in external magnetic fields ($\ll pb$)
- 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



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

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

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

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

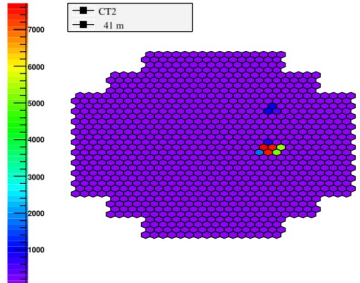
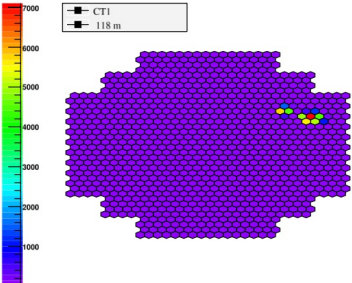
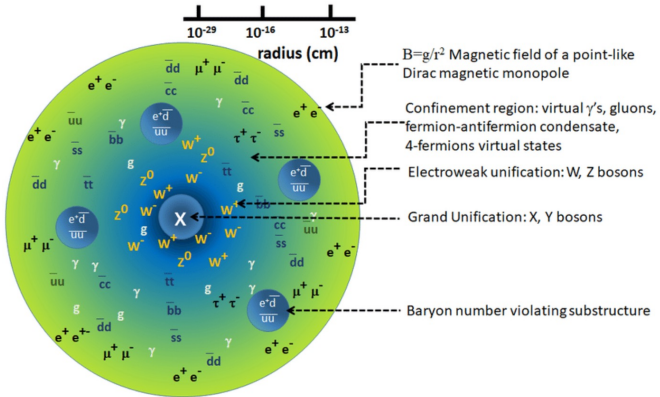
- Magnetic Monopoles make Maxwell's equation symmetric \rightarrow :-)

The Equation of Motion of the Monopoles

$$m \frac{d}{dt}(\gamma v) = gB - (f_p + mH\gamma) v$$

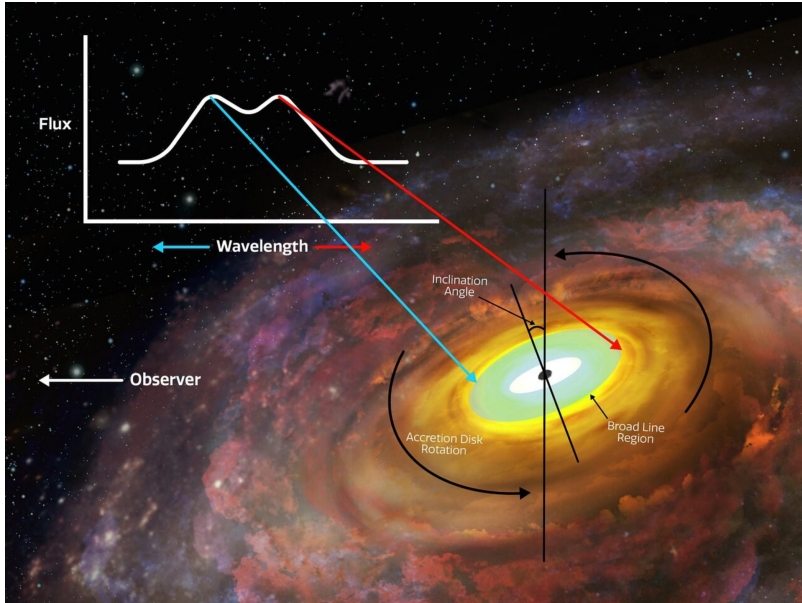
Acceleration in Intergalactic Magnetic Fields

- 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?

22

- These 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

- **Speaker:** Office n. 117, Paolotti Building michele.doro@unipd.it
- **Mail:** heap@lists.dfa.unipd.it
- **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

$$\eta = \frac{\Delta E}{\Delta mc^2}$$

Credit: **24**
Gabriele
Ghisellini

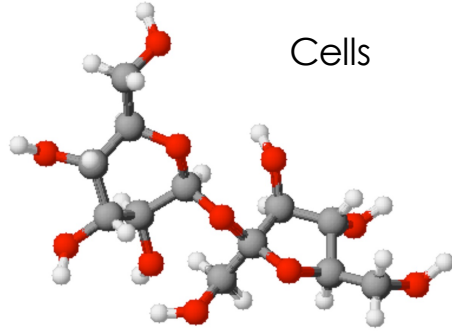


$$\eta = \frac{mgh}{mc^2} = \frac{980 \times 10^4 (h/100 \text{ m})}{9 \times 10^{20} \text{ erg}} \sim 10^{-14}$$



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

M. Doro - Gamma-ray Astronomy - IS



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

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

Fission

$^{235}_{92}\text{U}$ $^{142}_{56}\text{Ba}$ $^{92}_{36}\text{Kr}$

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

Fusion

Hydrogen-burning shell, Nonburning envelope, Helium ash

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

$$\eta = \frac{1}{2} \frac{GM}{R} \frac{m}{mc^2} = \frac{R_g}{2R} \quad (\text{Newton})$$

$R_{\text{min}} = R_g$ for max spin

$$\eta = 0.1 \text{ up to } 0.3 \text{ for accreting Kerr (Thorne 1974)}$$