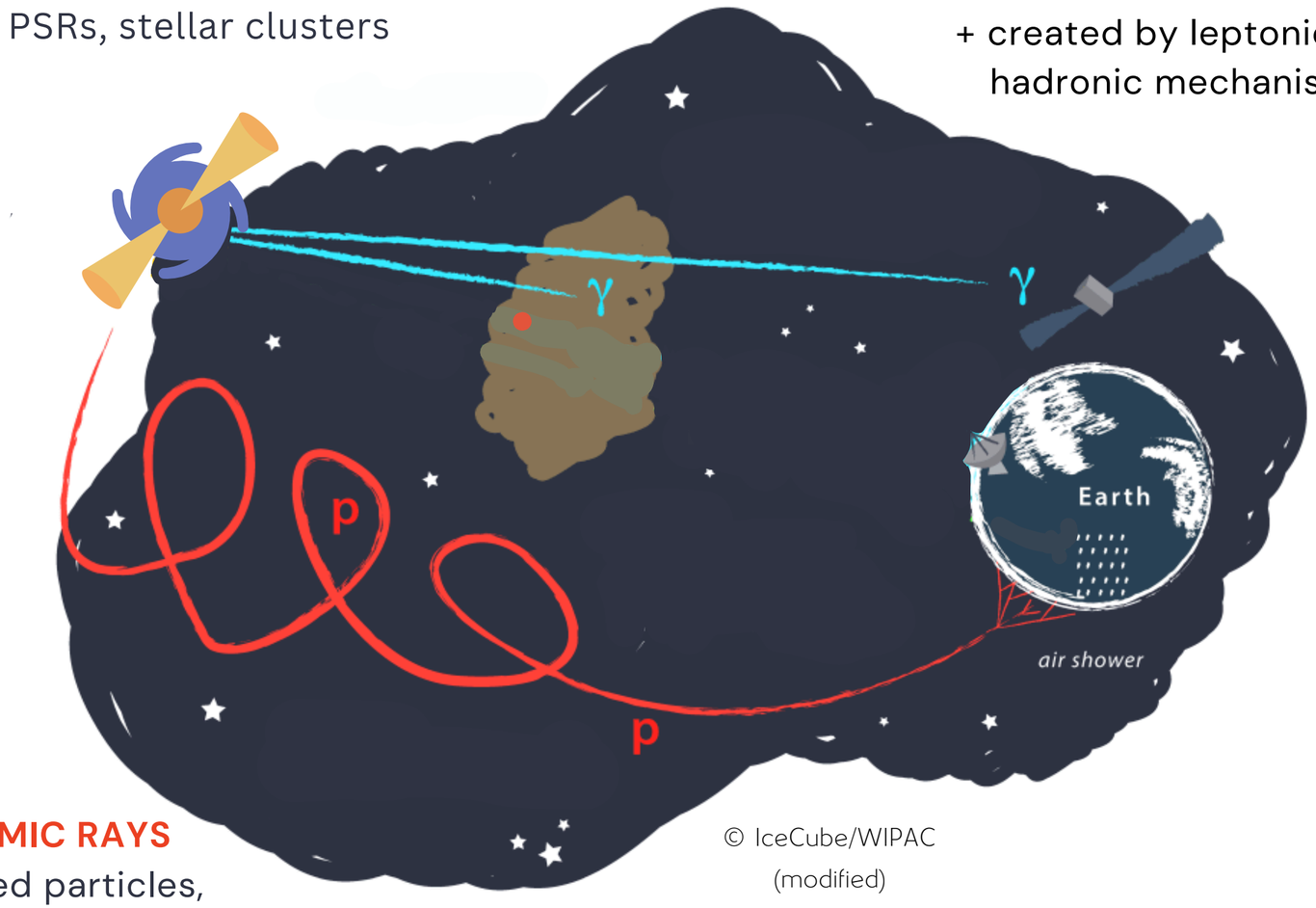
MULTIWAVELENGTH STUDY OF GALACTIC COSMIC-RAYS

Coline Dubos,
Tiina Suomijärvi
IJCLab
3rd PhD year, mail : coline.dubos@ijclab.in2p3.fr

INTRODUCTION

GALACTIC SOURCES
SNRs, PSRs, stellar clusters

GAMMA RAYS
Point to their sources
+ not absorbed in our Galaxy
+ created by leptonic and hadronic mechanisms



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COSMIC RAYS
Charged particles, deflected by magnetic fields

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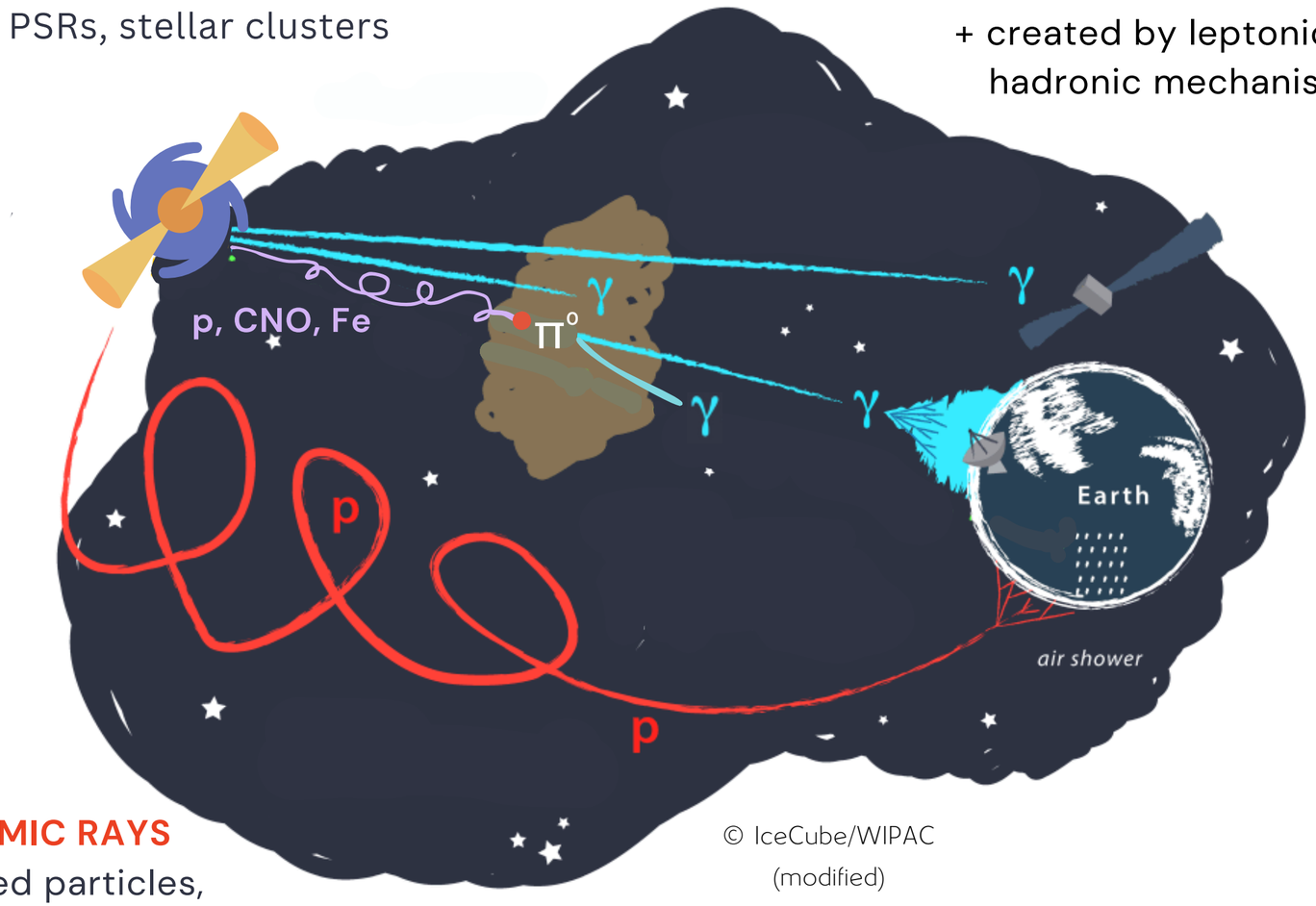

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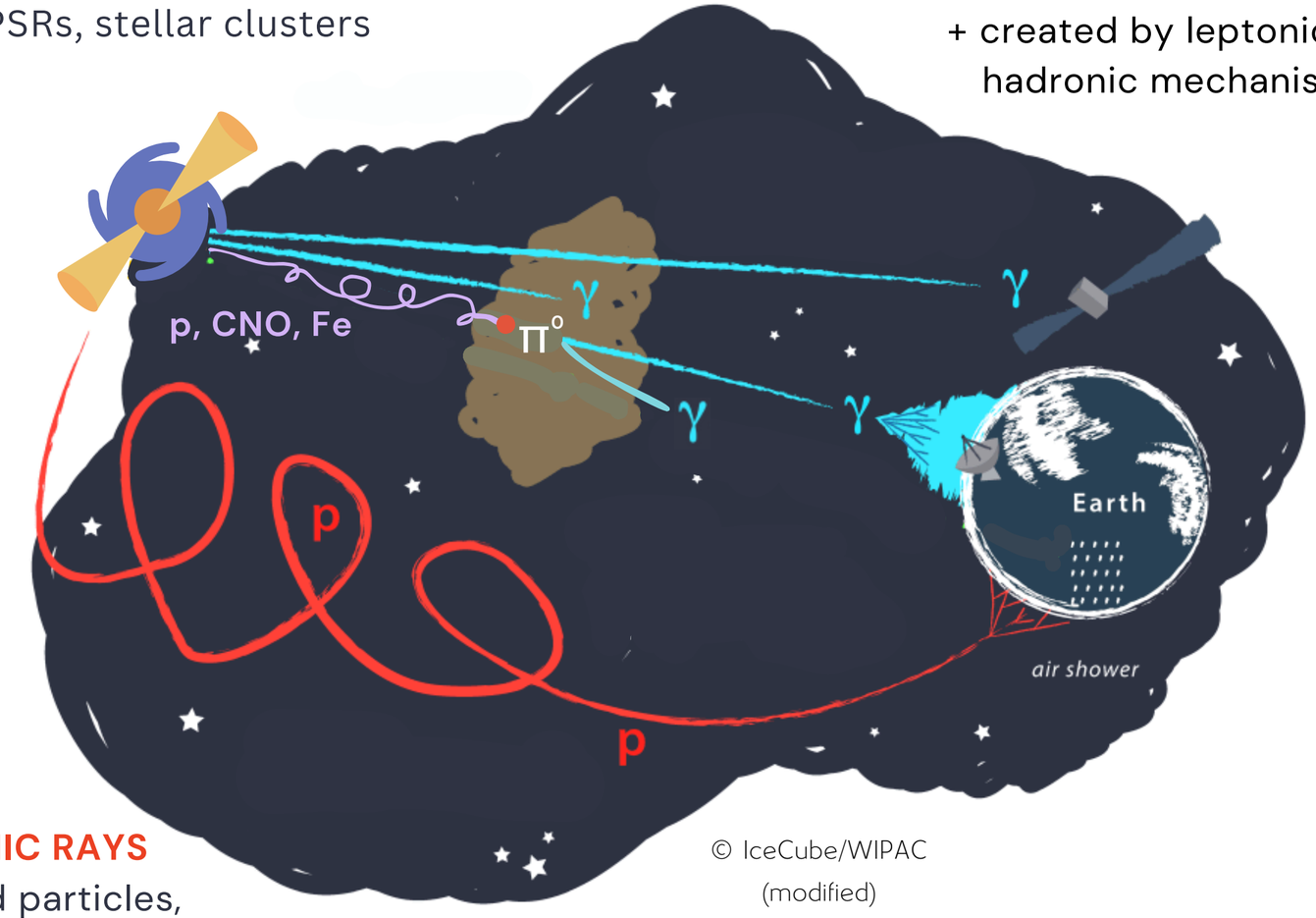

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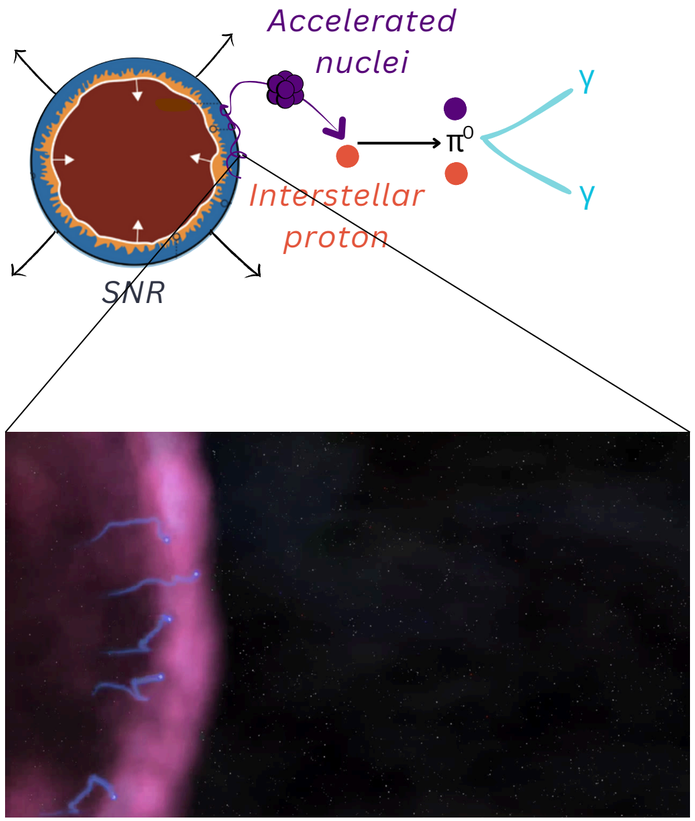
HADRONIC PROCESS FOR GAMMA-RAYS
CRs-proton interaction - Neutral pion decay process



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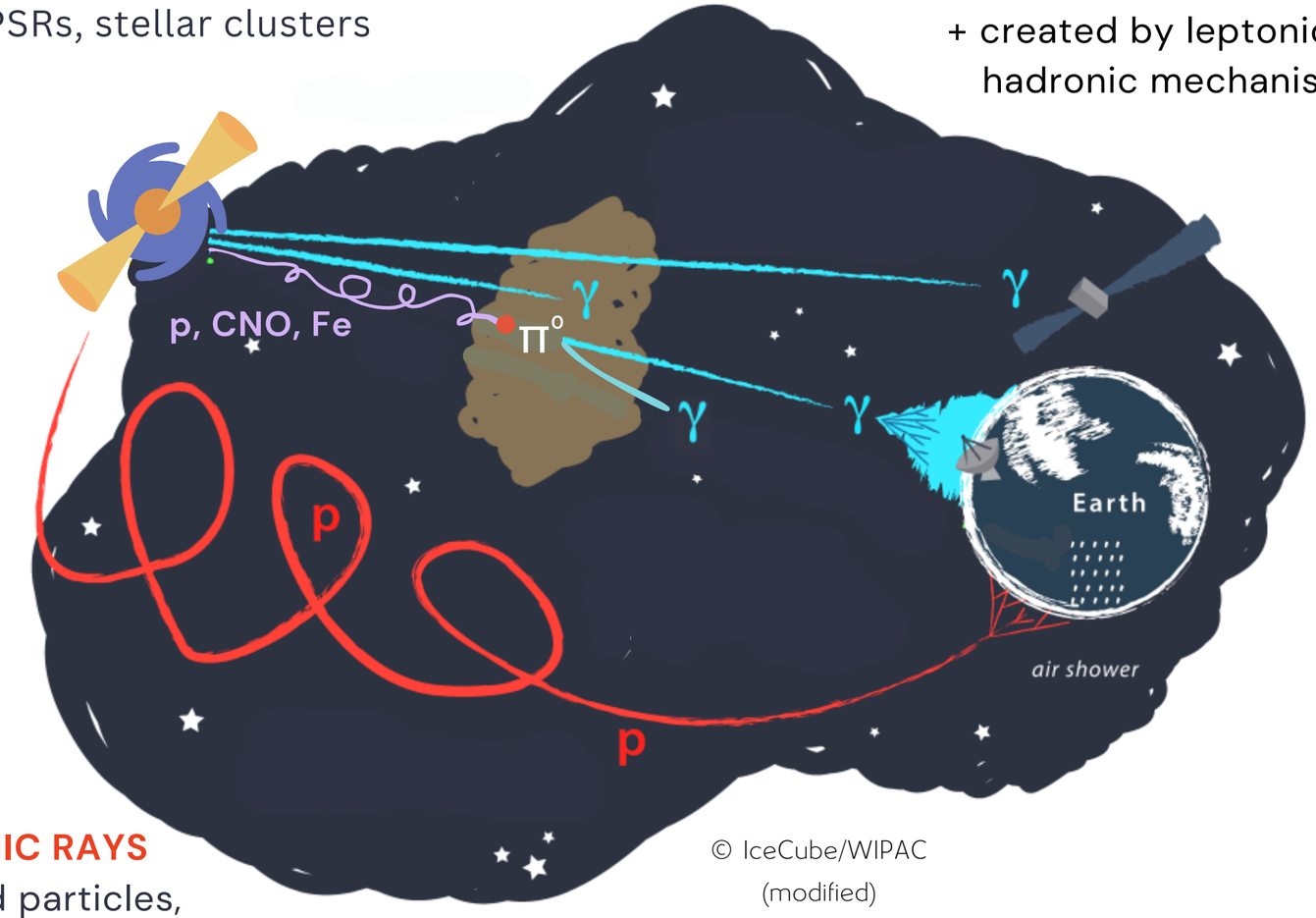

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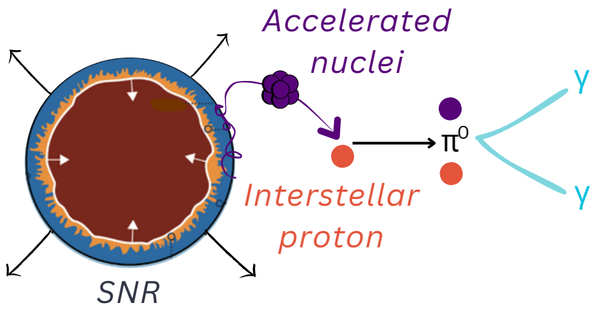
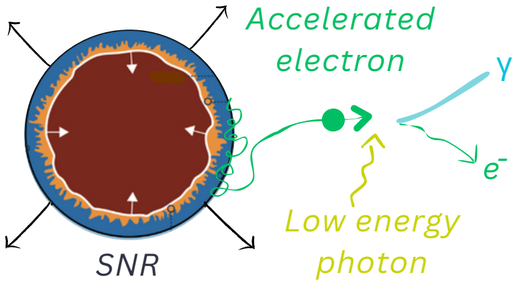


LEPTONIC PROCESS FOR GAMMA-RAYS
Synchrotron
Bremsstrahlung
Inverse Compton processes

Energy



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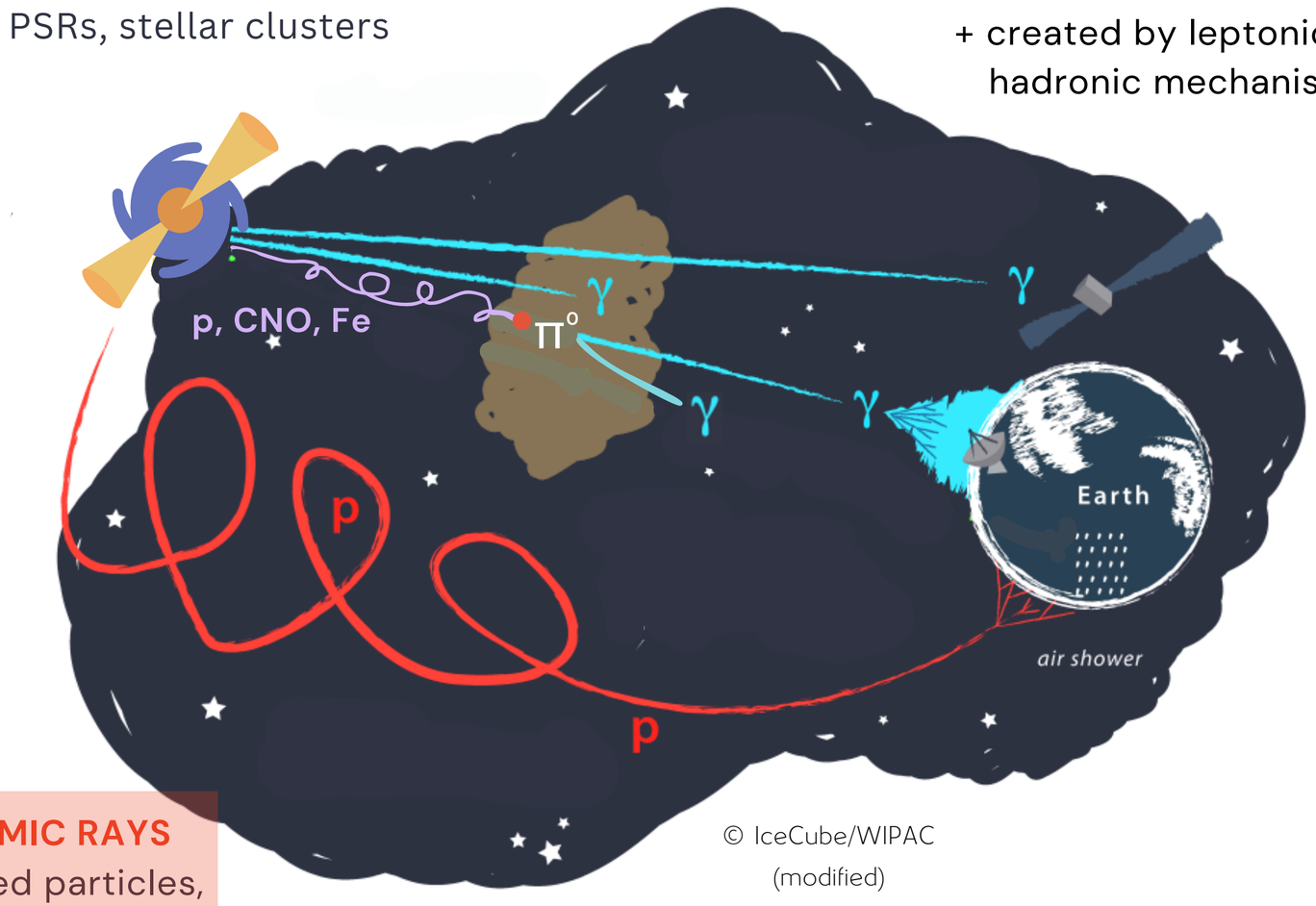

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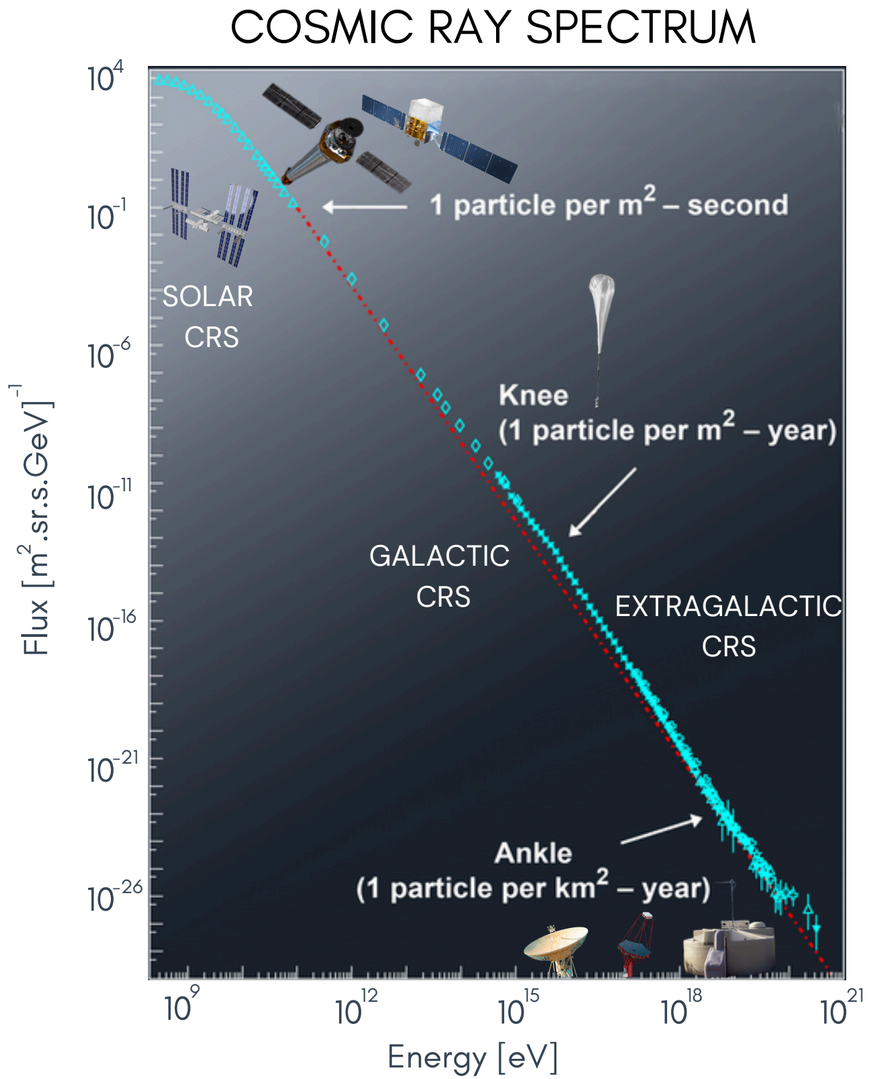
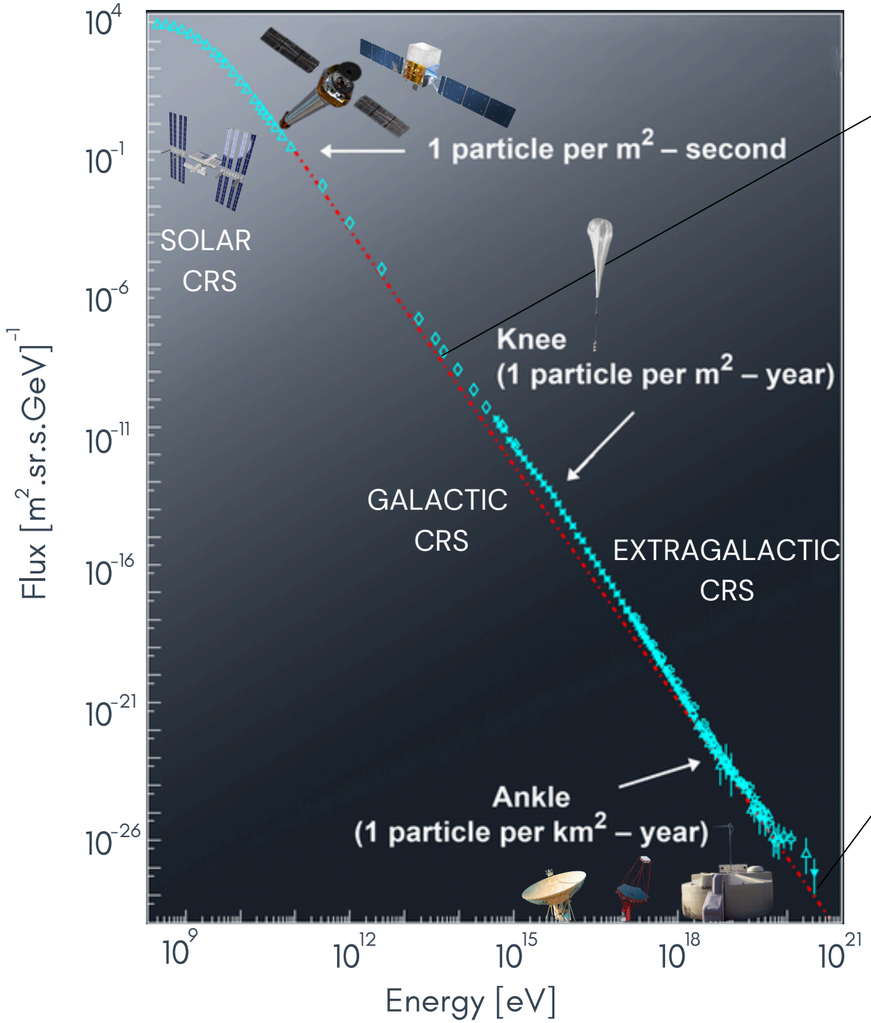


32 orders of magnitude!

12 orders of magnitude!

CONTEXT

COSMIC RAY SPECTRUM



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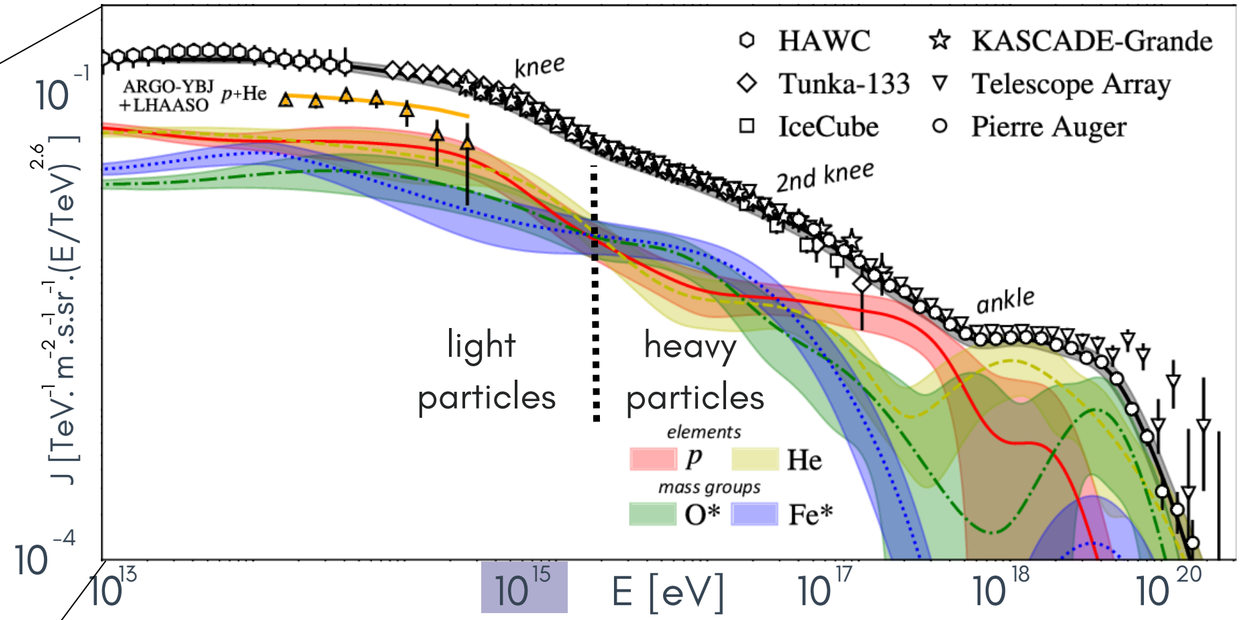
ALL-PARTICLE SPECTRUM



© Spectrum of cosmic-ray nucleons, kaon production, and the atmospheric muon charge ratio
Gaisser et al. 2012

CRs accelerated by Galactic sources? PeVatrons

<u>PeVatron candidates</u>:

Supernova Remnant

Stellar Cluster

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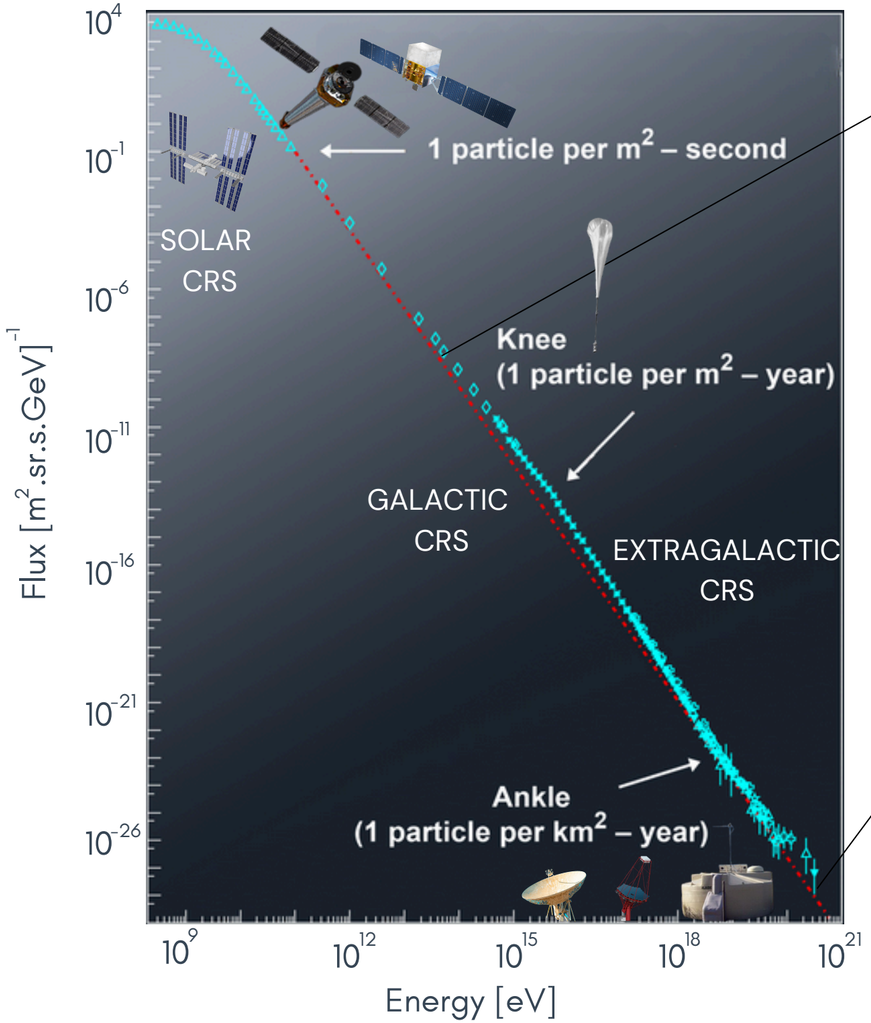

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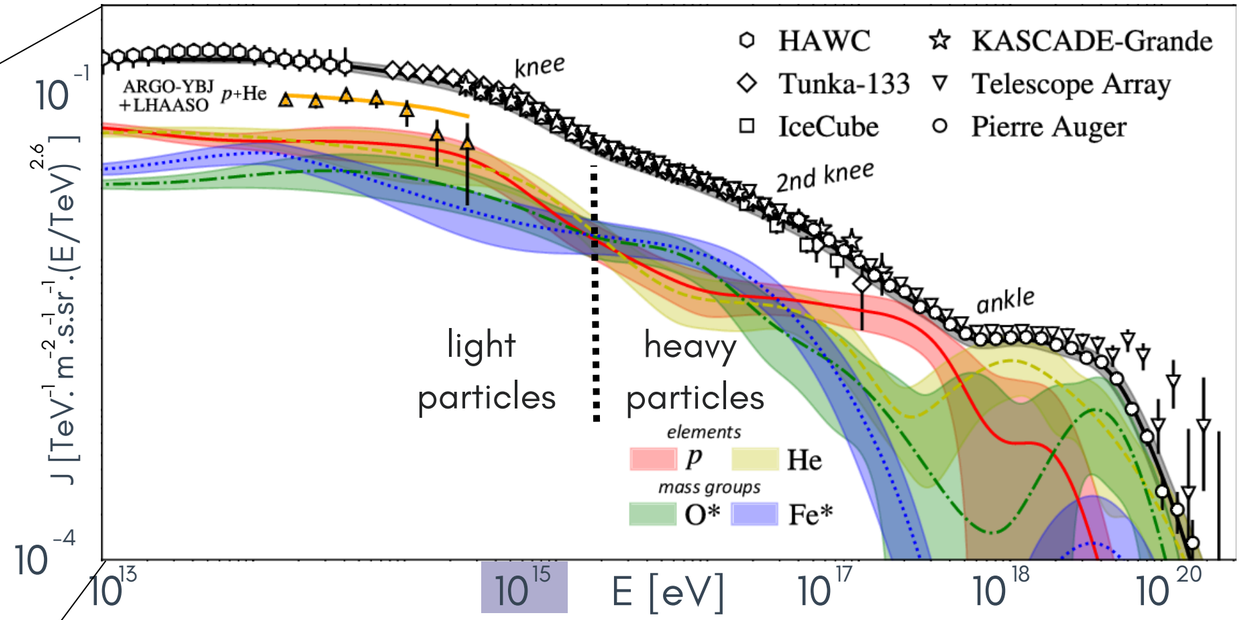

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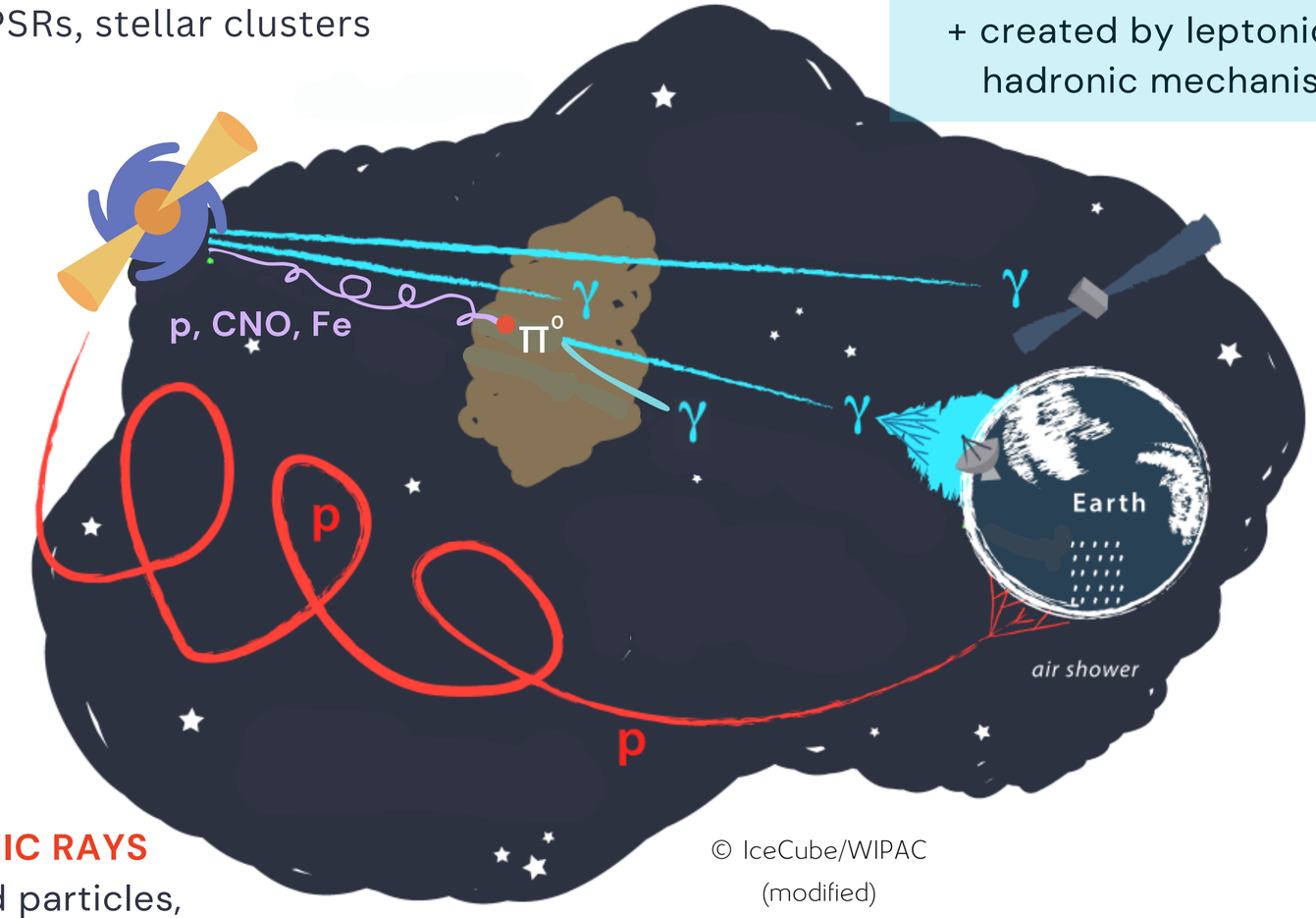

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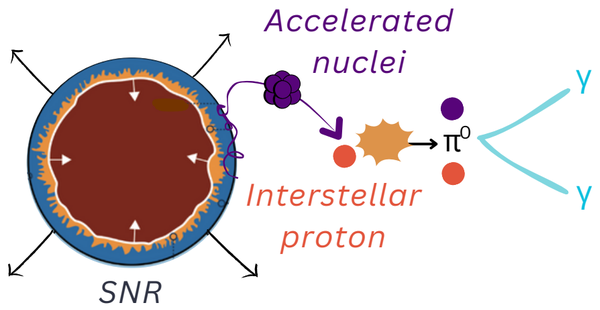

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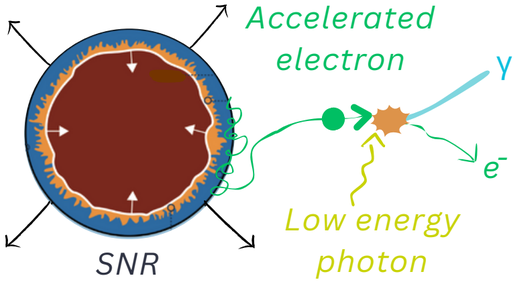
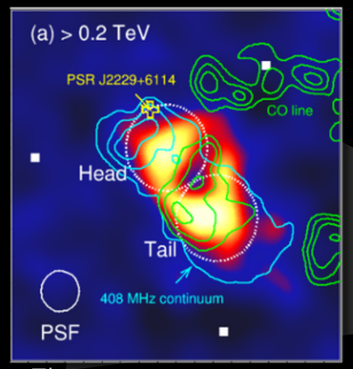


I - WHEN MODELS MEET DATA

MWL ANALYSIS OF THE SPECTRUM OF 2 SNRS

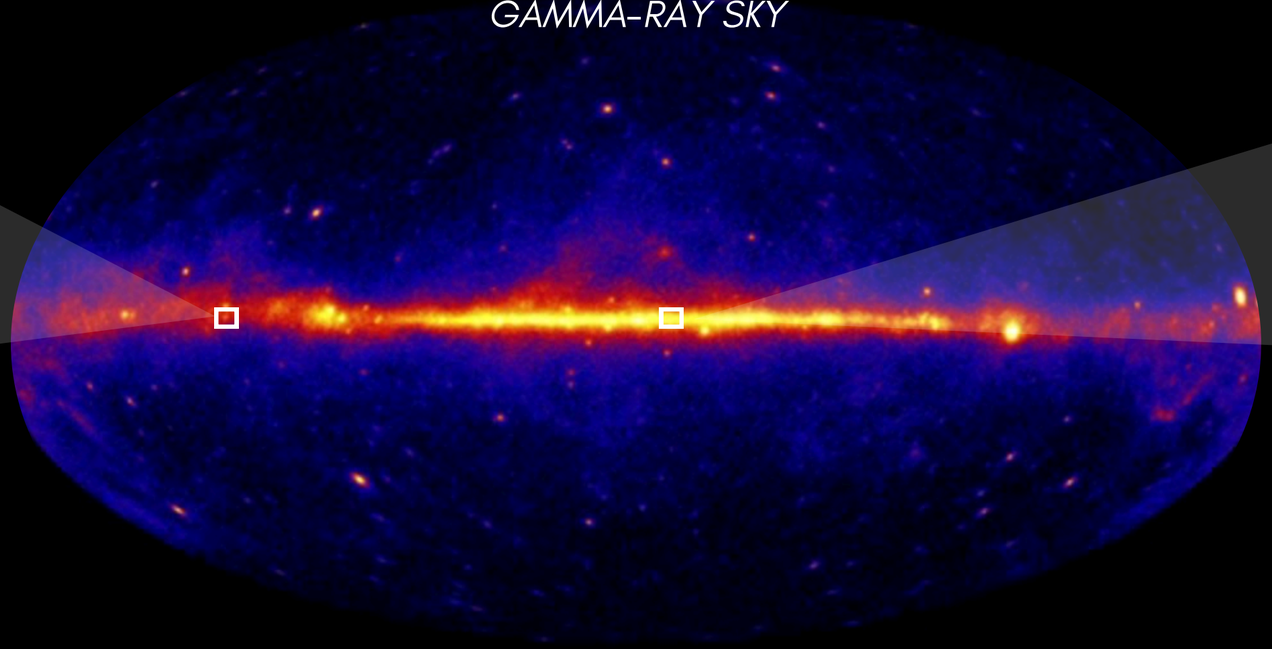
FERMI-LAT / VERITAS / LHAASO / HAWC TELESCOPES

SNR | HAWC J2227+610



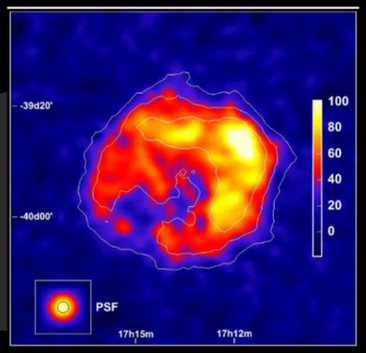
The γ-ray supernova G106.3+2.7
MAGIC collaboration 2022

GAMMA-RAY SKY



FERMI / H.E.S.S. TELESCOPES

RX J1713.7-3946 | SNR



A detailed spectral and morphological study of the gamma-ray supernova remnant RX J1713.7-3946 with H.E.S.S
HESS Collaboration 2005

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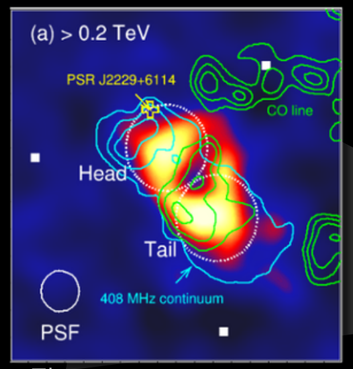

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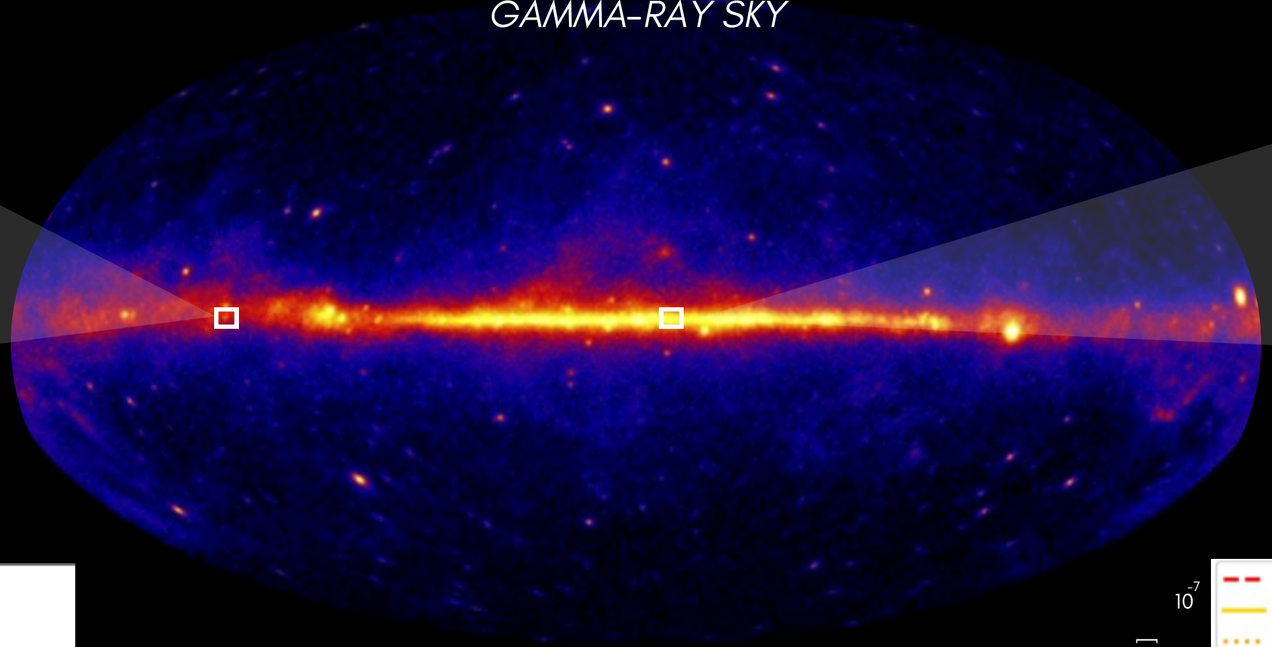

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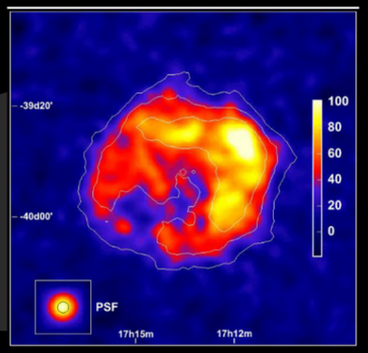

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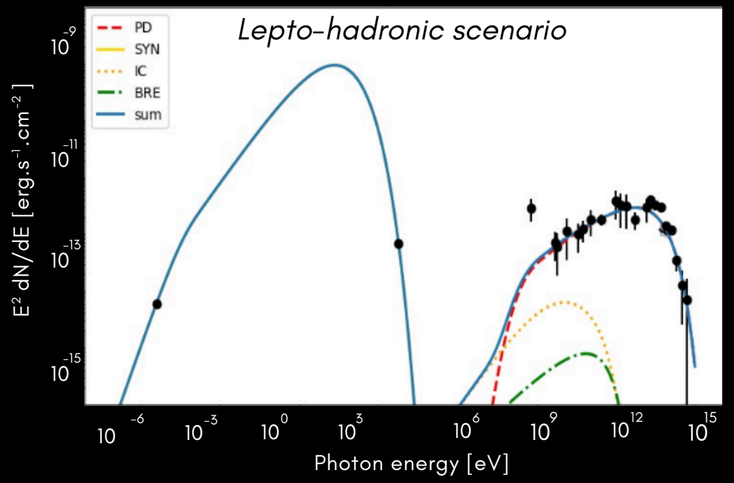
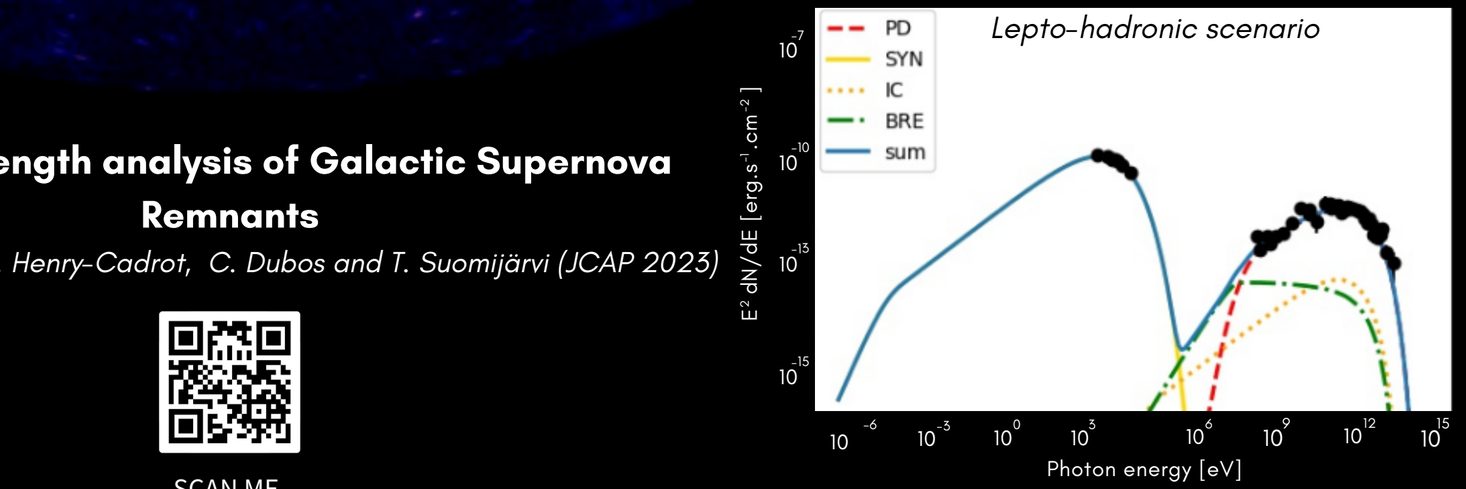


Multiwavelength analysis of Galactic Supernova Remnants

P. Sharma, Z. Ou, C. Henry-Cadrot, C. Dubos and T. Suomijärvi (JCAP 2023)

SCAN ME



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MWL ANALYSIS OF THE SPECTRUM OF 2 SNRS

Dominant hadronic contribution at high energies

FERMI-LAT / VERITAS / LHAASO / HAWC TELESCOPES

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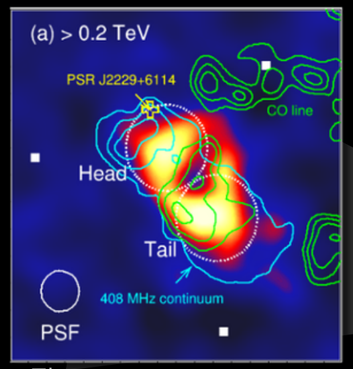

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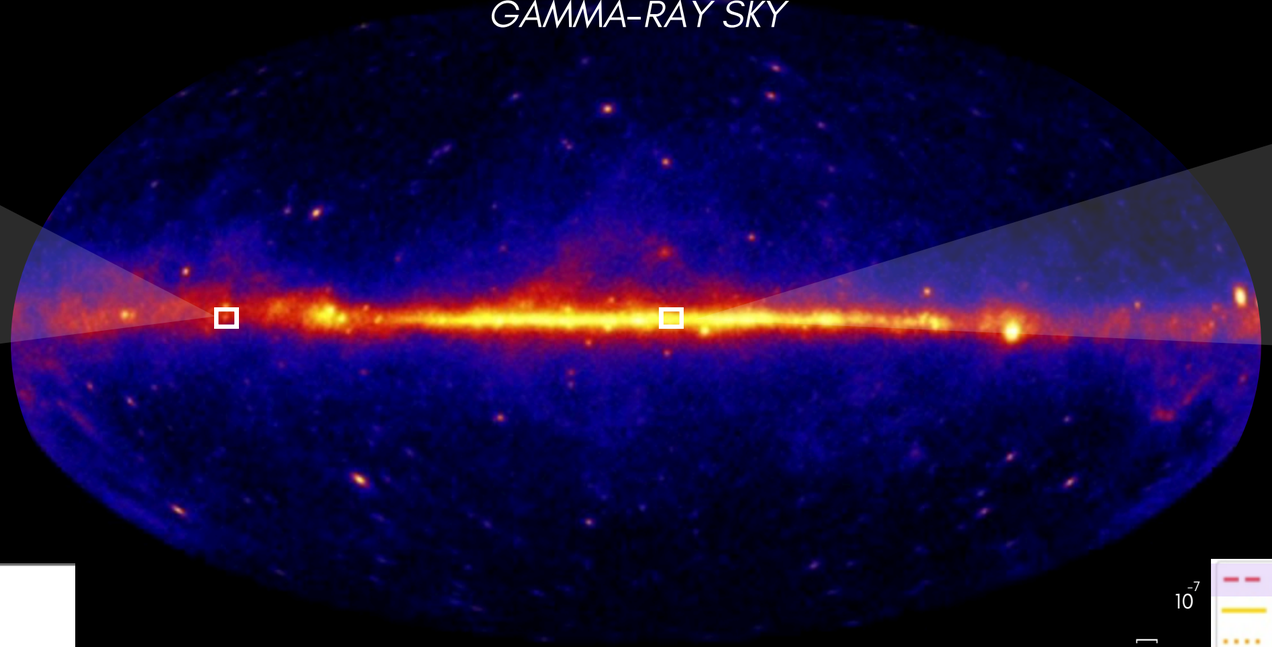

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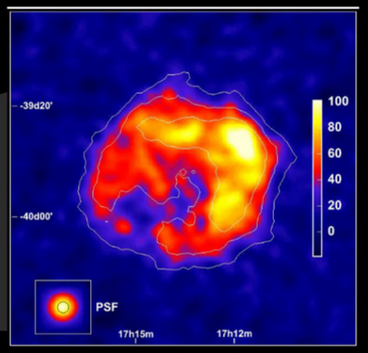

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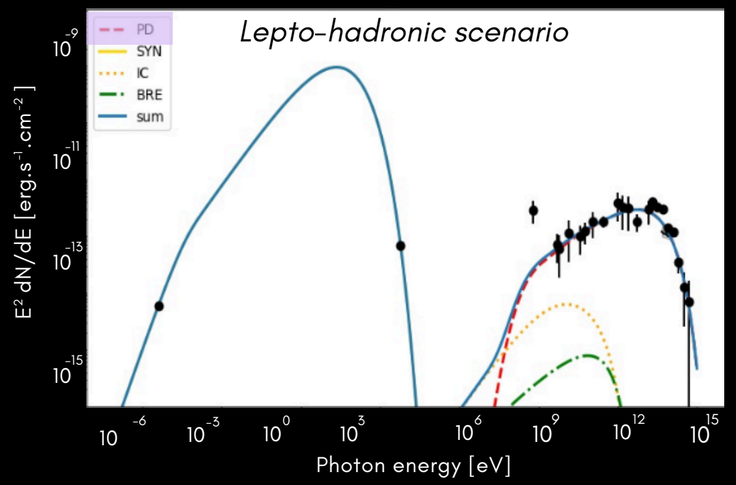

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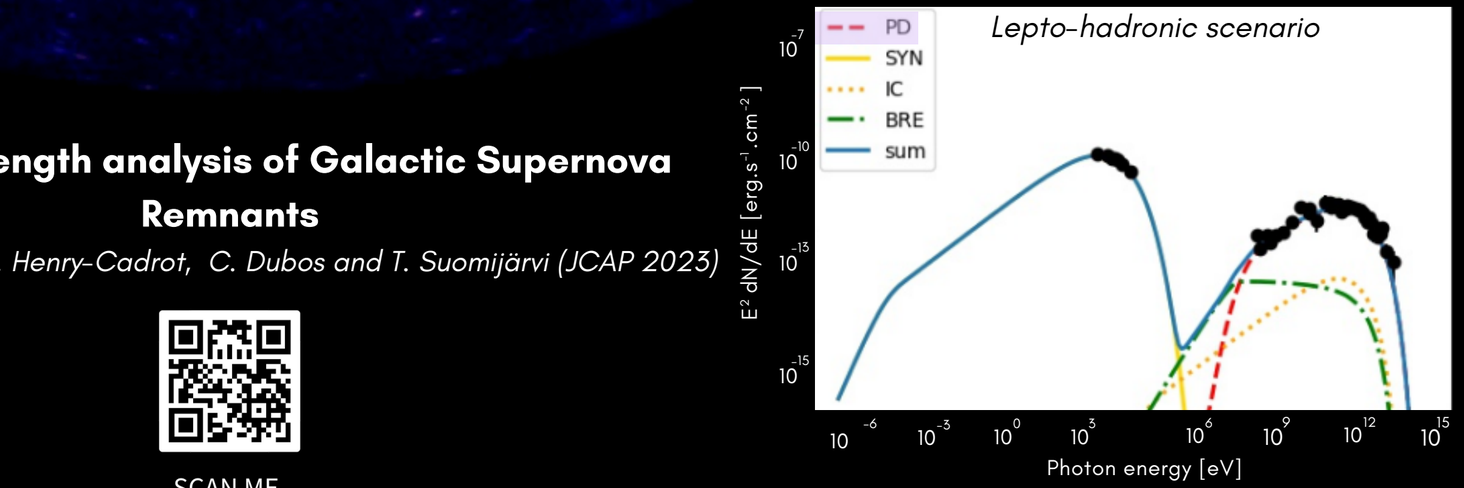


I - WHEN MODELS MEET DATA

HEAVY CR PION DECAY MODELLING

γπ GAMMAPY - NAIMA

Photon flux emitted from CR distribution

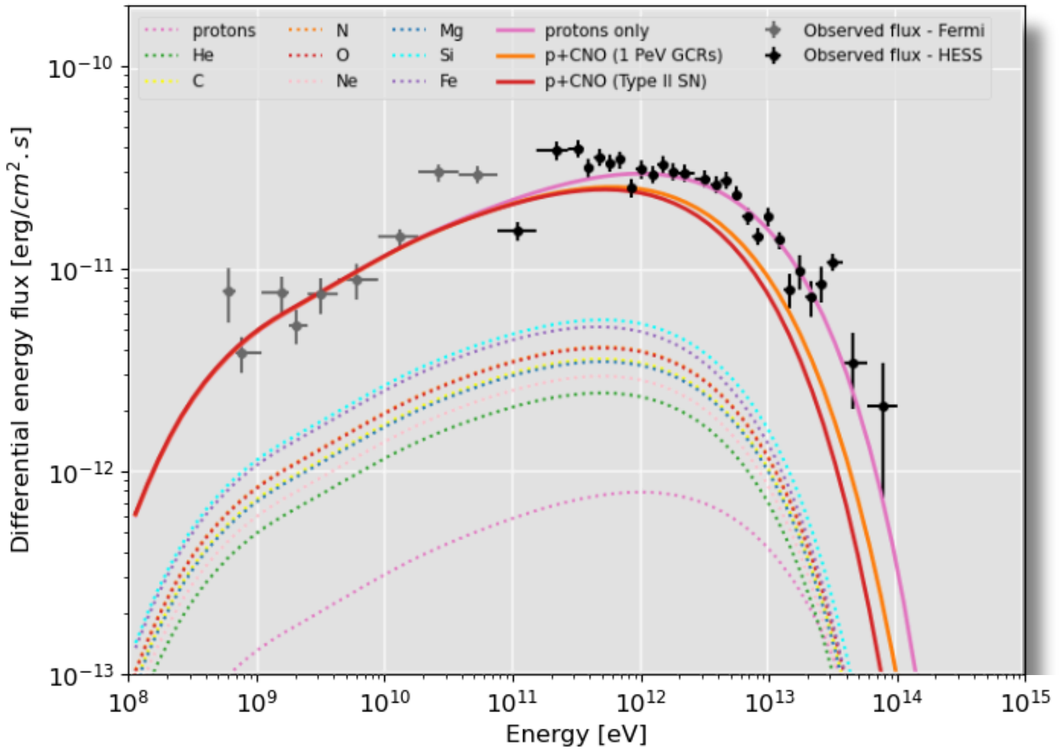
$$F(E) = f.\sigma.\mathbf{N_H}.\mathbf{A_m}.(E/\mathbf{E_0})^{-\alpha}.e^{-(E/Z.\mathbf{E_c}/A)^{\beta}}$$

$\mathbf{N_H}$: number density of the target protons
$\mathbf{A_m}$: amplitude of the proton distribution
$\mathbf{E_0}$: reference energy

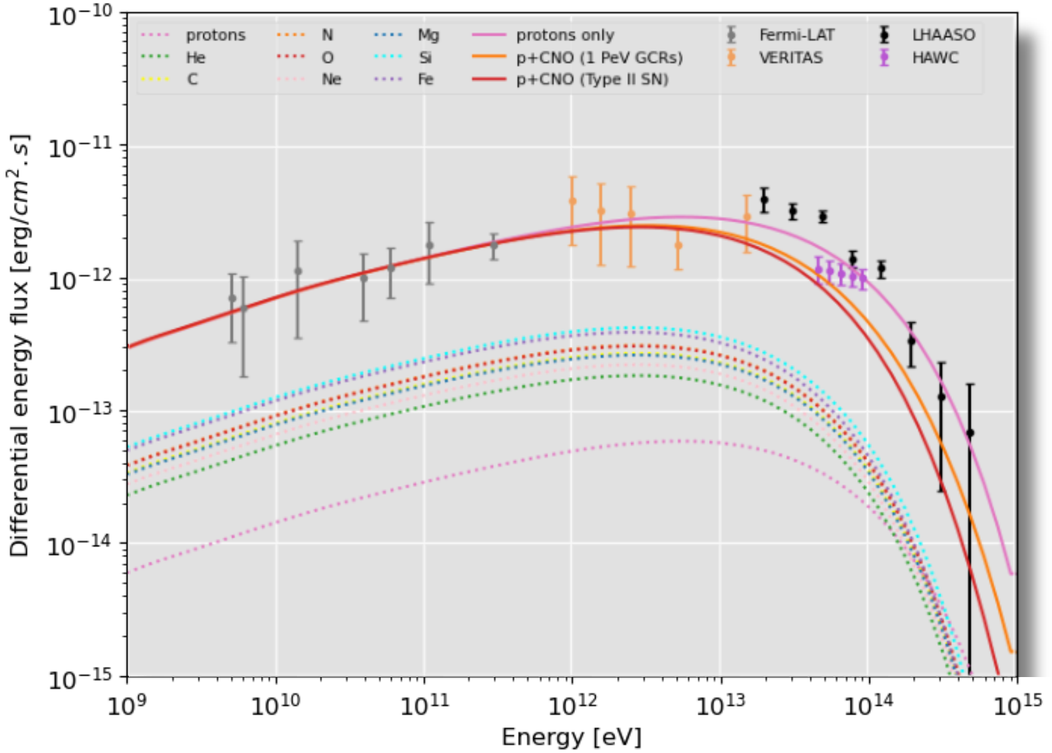
$\boldsymbol{\alpha}$: proton spectral index
$\mathbf{E_c}$: proton cut-off energy
$\boldsymbol{\beta}$: cut-off exponent

Spectral parameters fixed by the MWL analysis

γ spectrum of **RX J1713.7-3946**



γ spectrum **HAWC J2227+610**



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HEAVY CR PION DECAY MODELLING

Photon flux emitted from CR distribution

$$F(E) = \mathbf{f}.\boldsymbol{\sigma}.N_H.A_m.(E/E_0)^{-\alpha}.e^{-(E/\mathbf{Z}.E_c/\mathbf{A})^{\beta}}$$

f: fraction of the CRs abundances

σ: inelastic cross-section

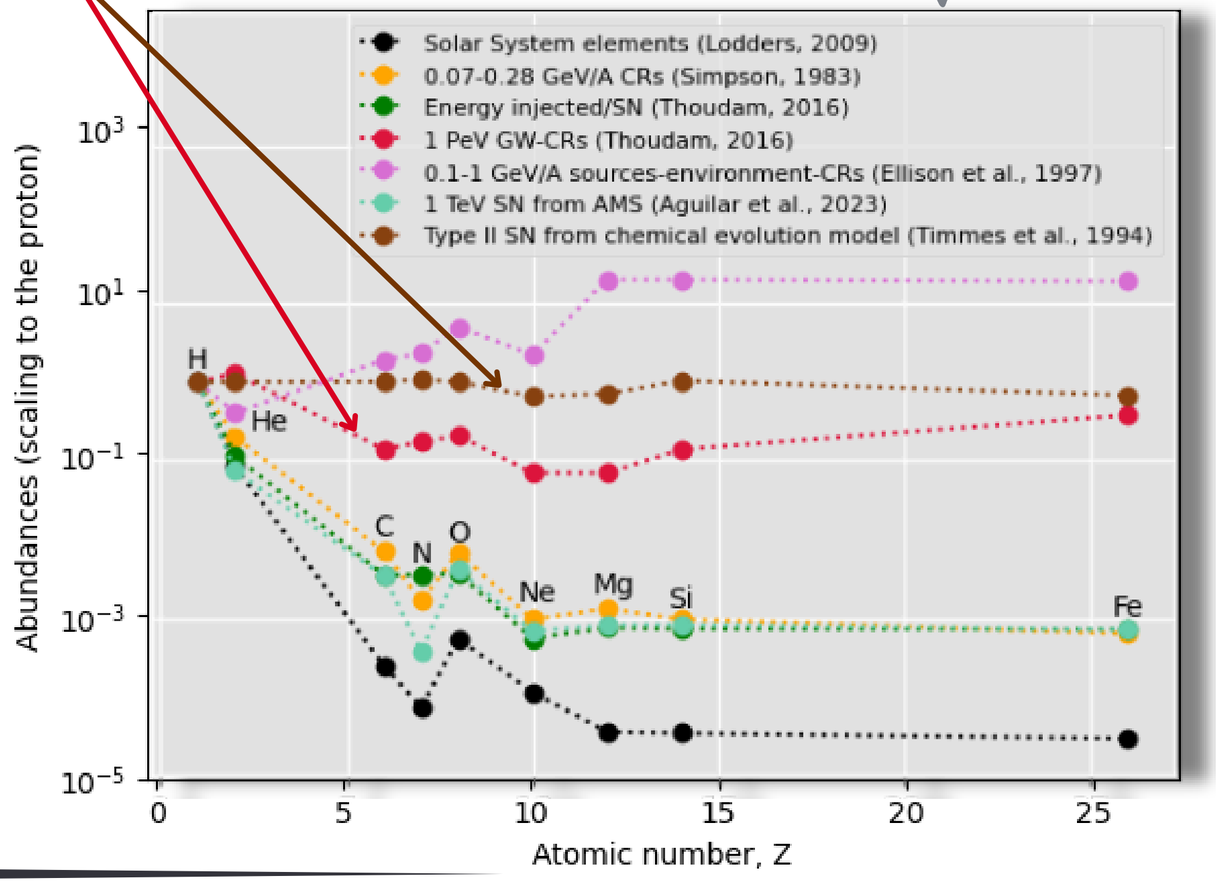
Z: CR charge

A: CR mass number

2 different CR composition used for this study, linked to:

- the source: **Type II Supernova (SN)**
- or the acceleration of the GCRs: **1 PeV CRs**

CR abundance curves



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$\gamma\pi$ GAMMAPY - NAIMA

Pion decay model considering CRs of:
- **protons only**
- **protons + CNO with a 1 PeV CRs**
- **protons + CNO with a type II SN**

composition

N_H: number density of the target protons
A_m: amplitude of the proton distribution
E_0 : reference energy

α: proton spectral index
E_c : proton cut-off energy
β: cut-off exponent

Spectral parameters fixed by the MWL analysis

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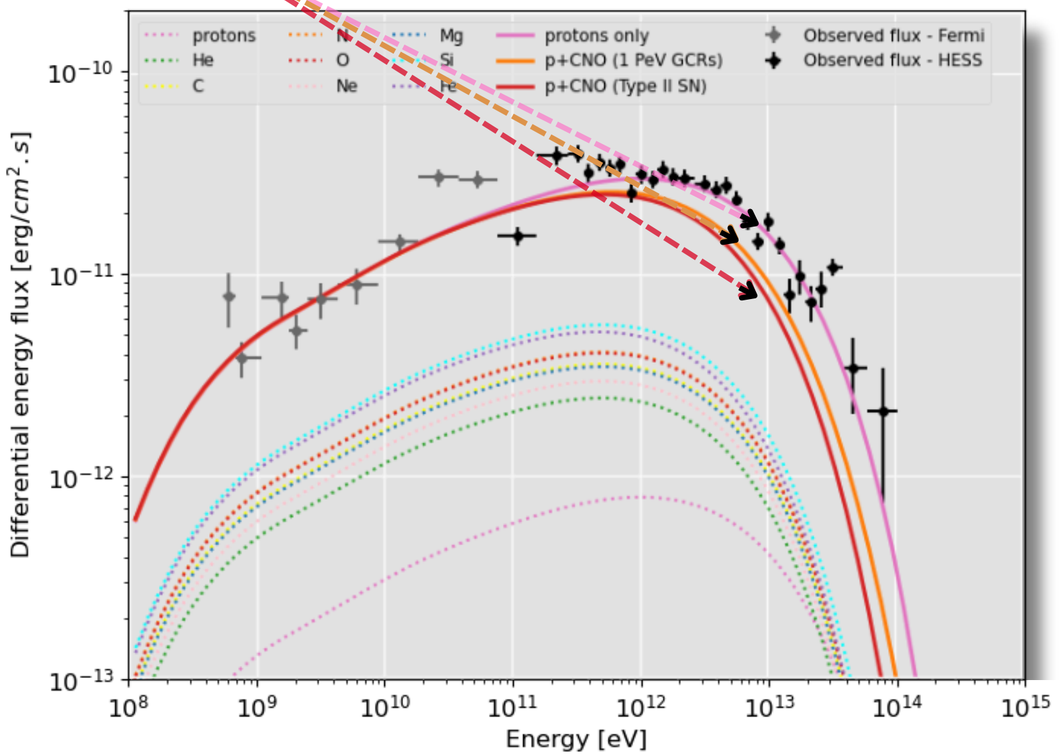
Z: CR charge
A: CR mass number

γ spectrum of **RX J1713.7-3946**



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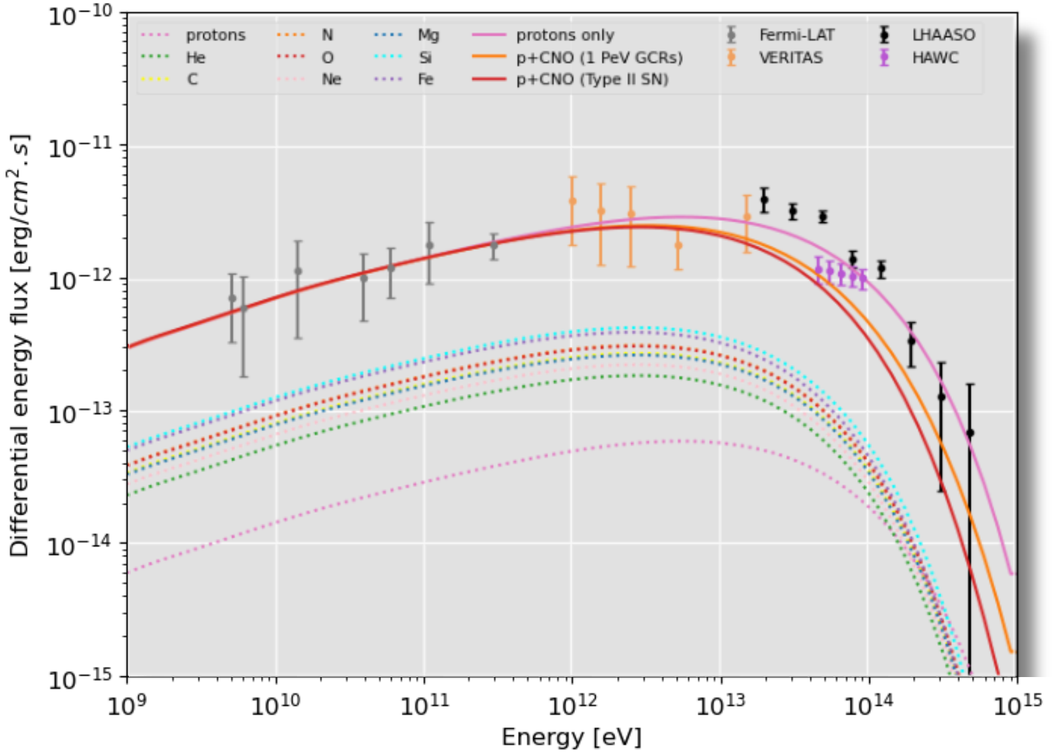
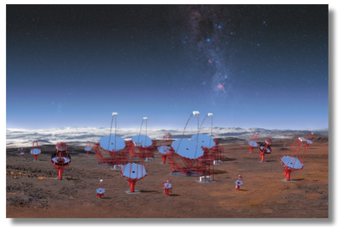


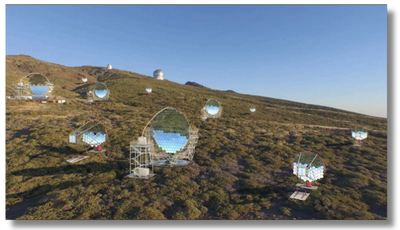
II - WHEN CTAO SIMULATIONS MEET MODELS

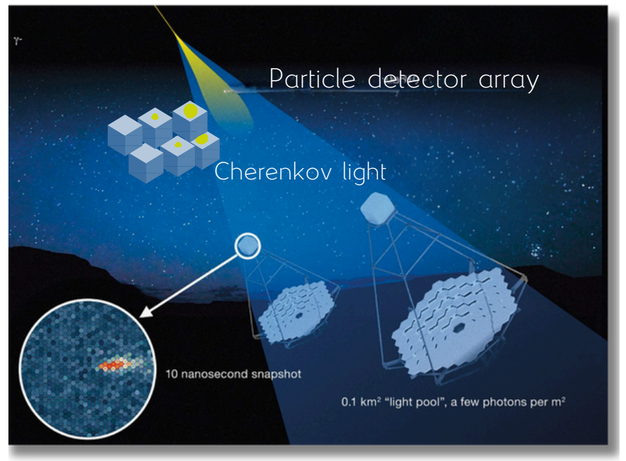
GAMMAPY - NAIMA

South site
Chile



North site
Canary Island





Gamma Ray
Atmosphere
Air Shower
Primary Gamma Ray

gamma ray interacts with the atmosphere

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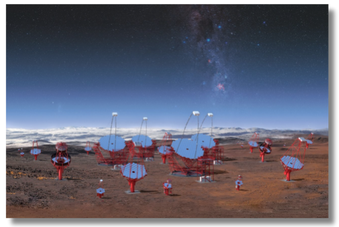

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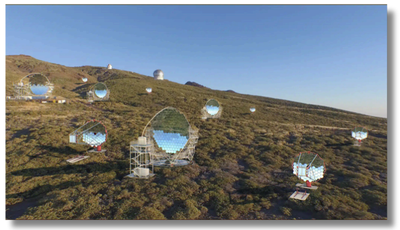
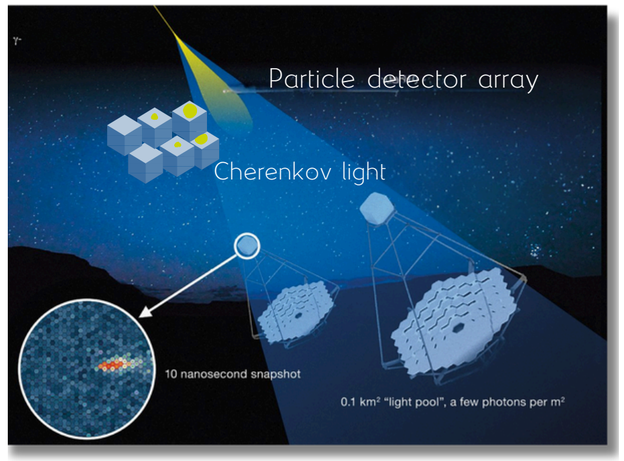


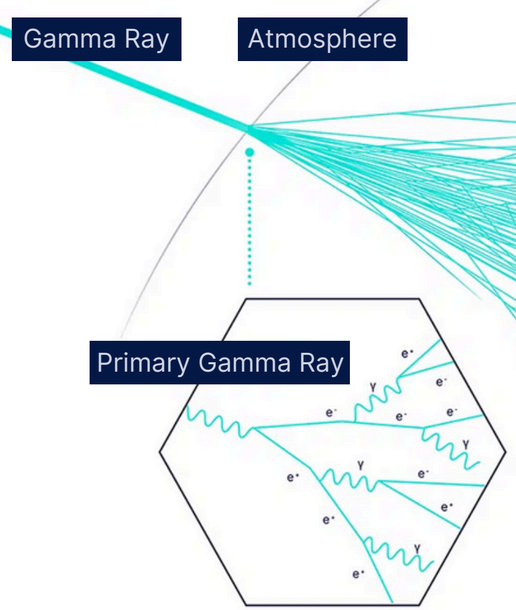


How to perform CTAO simulations of γ spectrum with Gammapy?

- Instrument Response Function (IRF): **prod5 v0.1**
Monte Carlo simulations of the γ-ray shower
⟶ zenith angle / observation time: **50h** / South site (14 MSTs + 37 SSTs)

- Consideration of the background: **1D On-Off analysis**

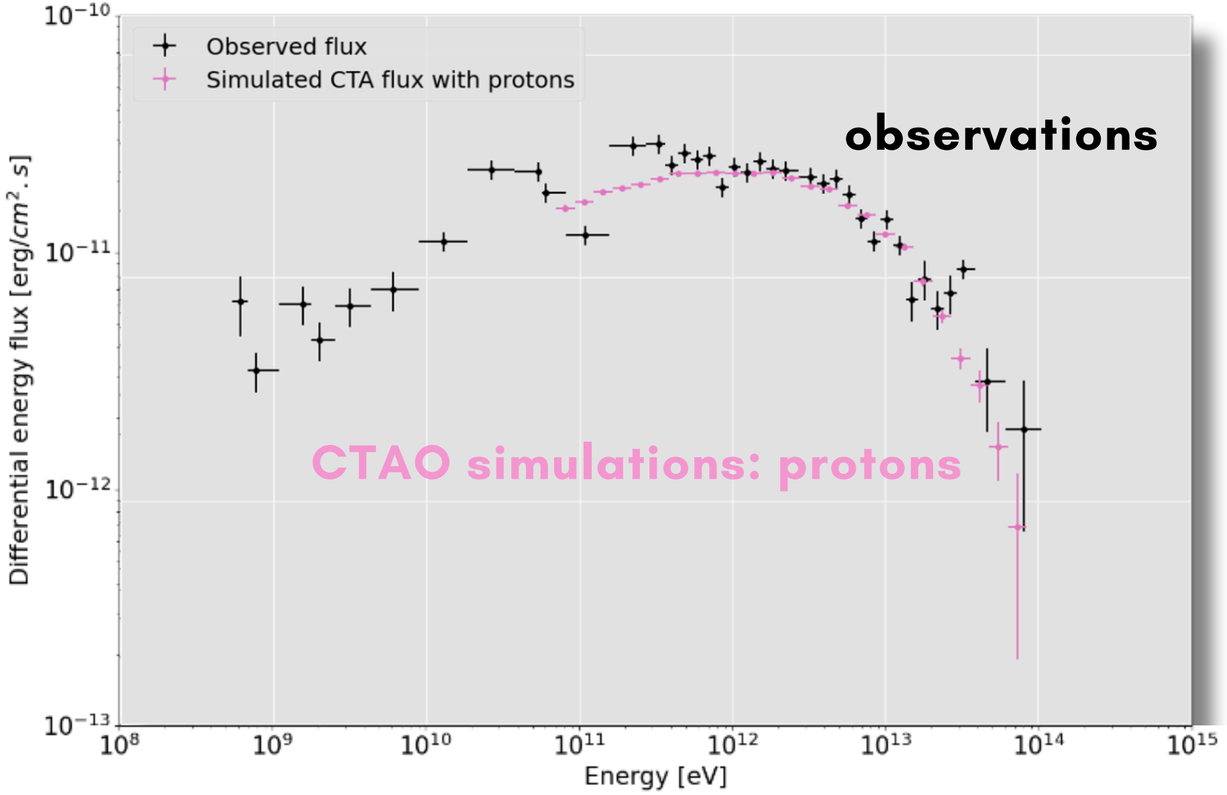
- Input radiative models: pion decay considering CRs of:
⟶ protons only
⟶ **CNO with 1 PeV CR** composition
⟶ **CNO with a type II SN** composition
⟶ **Fe with a type II SN** composition



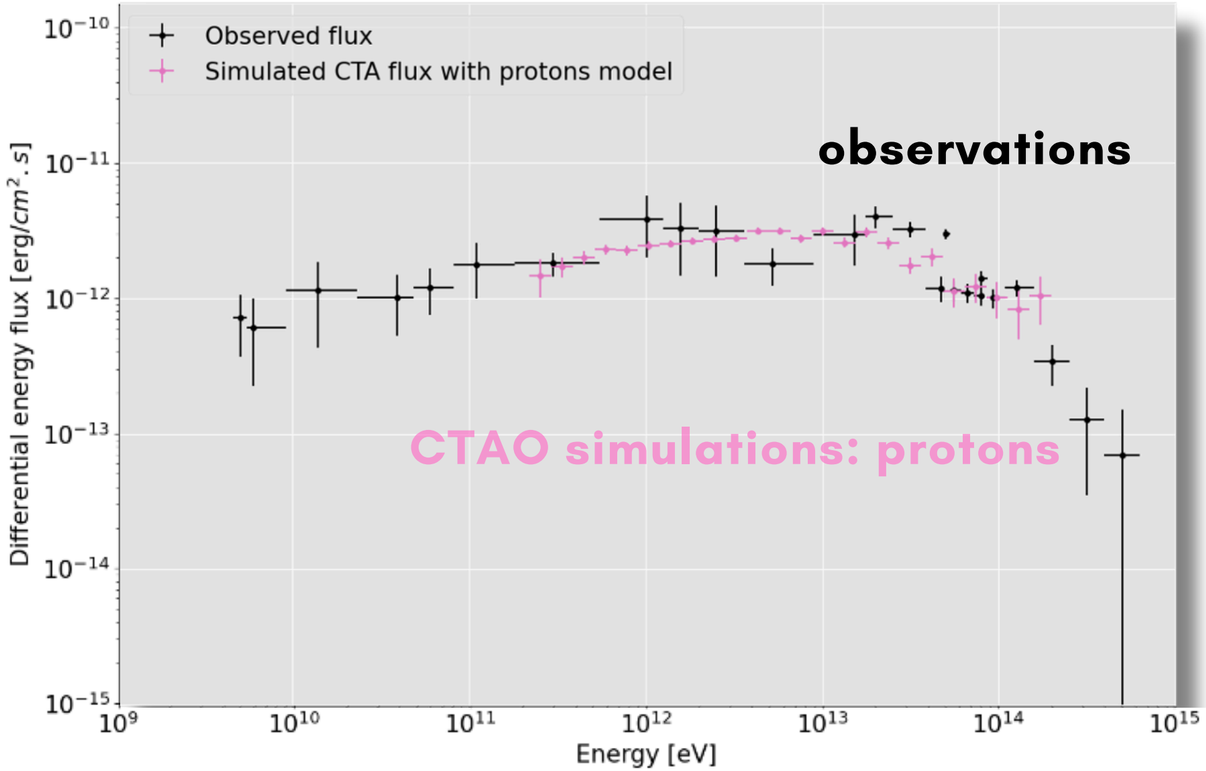
gamma ray interacts with the atmosphere

II - WHEN CTAO SIMULATIONS MEET MODELS

RX J1713.7-3946



HAWC J2227+610



III - CAN CTAO DETECT CRs FROM SNRs?

Can we separate the studied models?

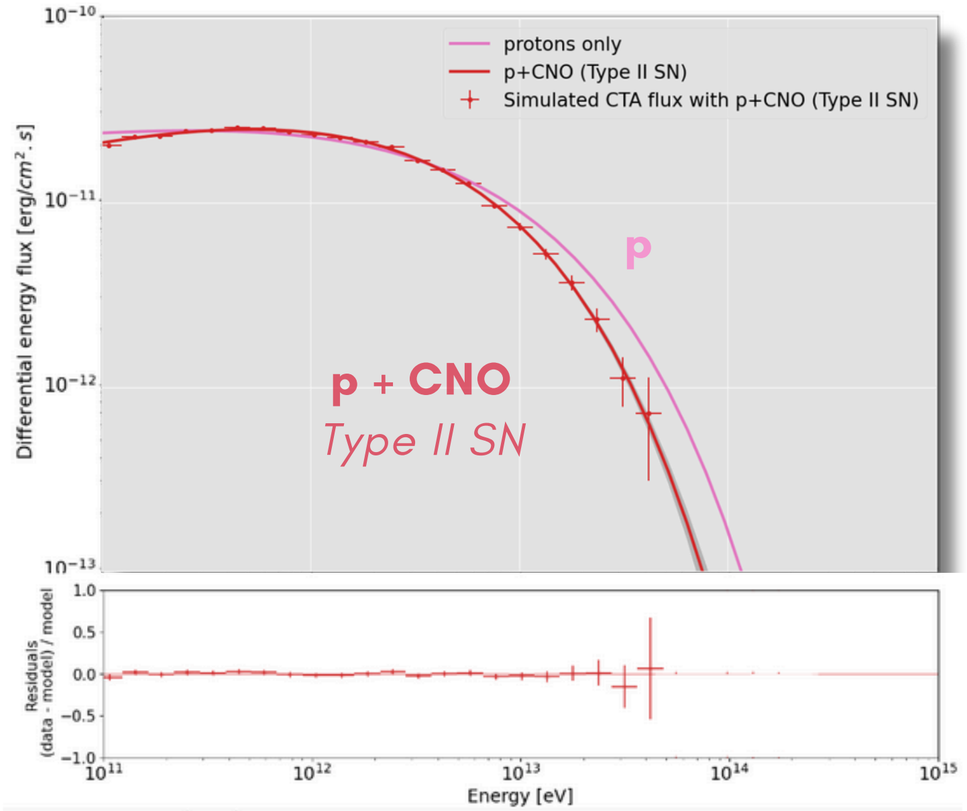
Data fitting: if Log-Likelihood test **ΔTS > 29 (5σ)** (2 free parameters) => the models are distinguished

III - CAN CTAO DETECT CRs FROM SNRs?

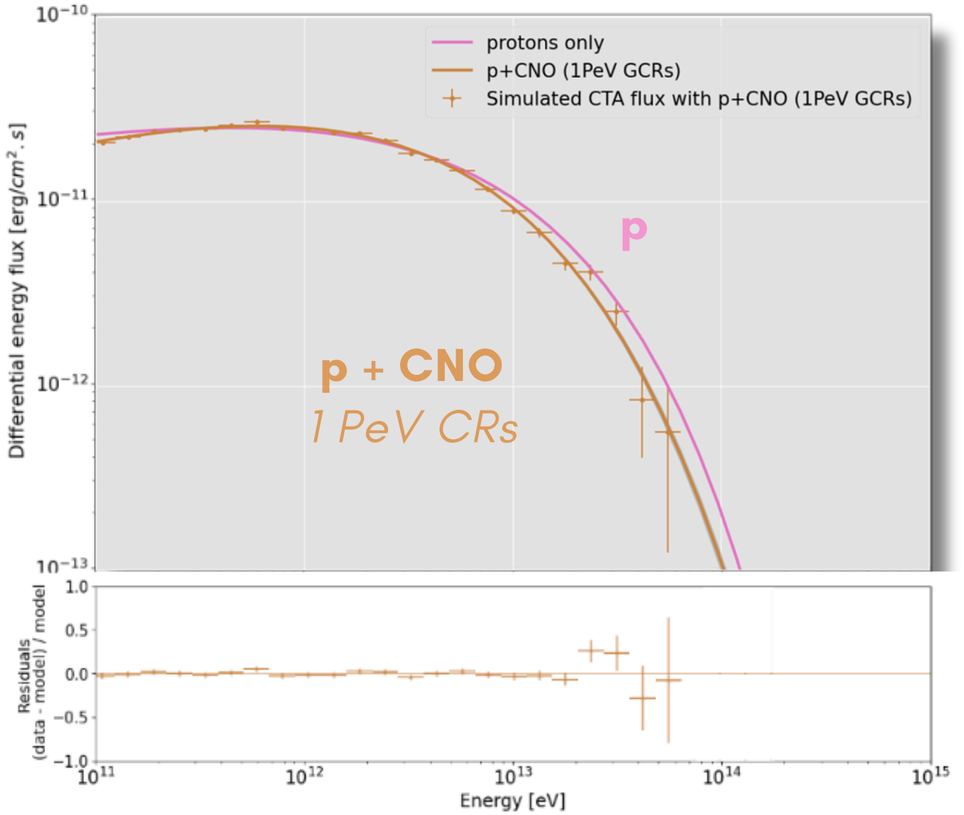
Can we separate the studied models?

Data fitting: if Log-Likelihood test **ΔTS > 29 (5σ)** (2 free parameters) => the models are distinguished

CTAO simulations of **RX J1713.7-3946** (A_m and α are free during the fit)



ΔTS = 202 ✓



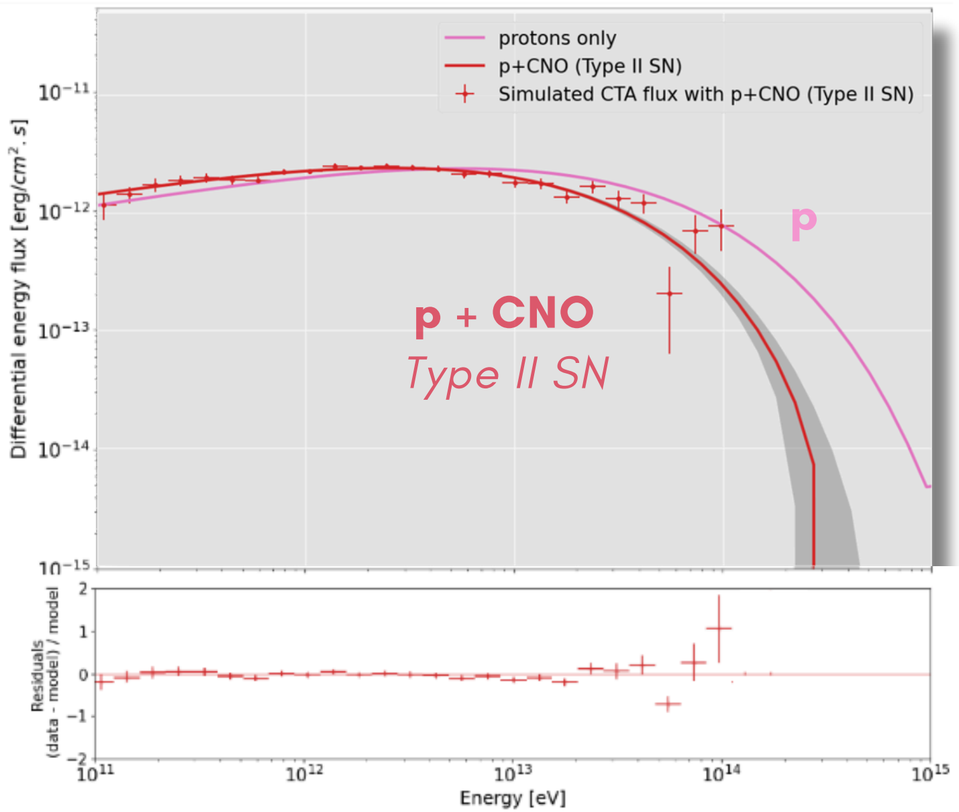
ΔTS = 102 ✓

III - CAN CTAO DETECT CRs FROM SNRs?

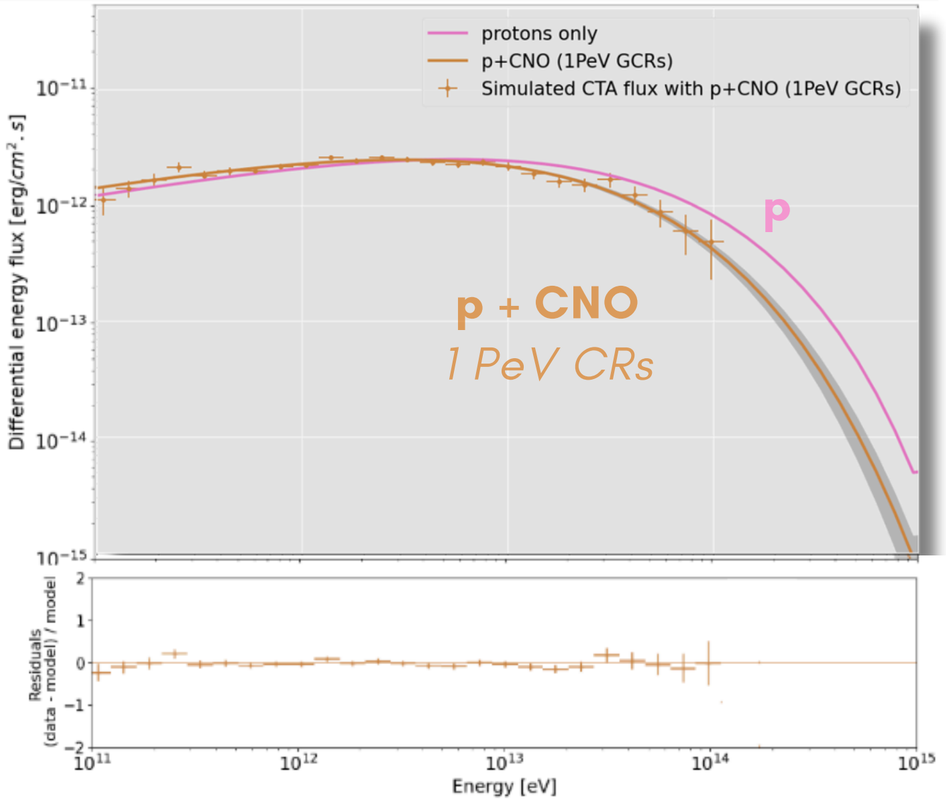
Can we separate the studied models?

Data fitting: if Log-Likelihood test **ΔTS > 25 (5σ)** (1 free parameter) => the models are distinguished

CTAO simulations of **HAWC J2227+610** (A_m is free during the fit)



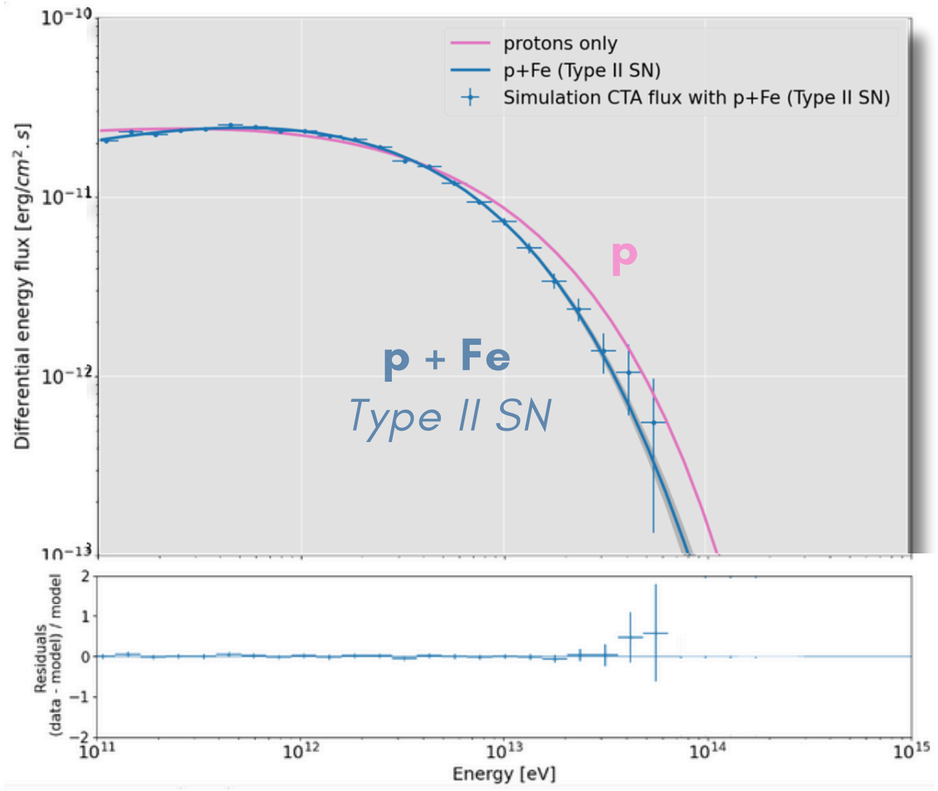
ΔTS = 113



ΔTS = 53

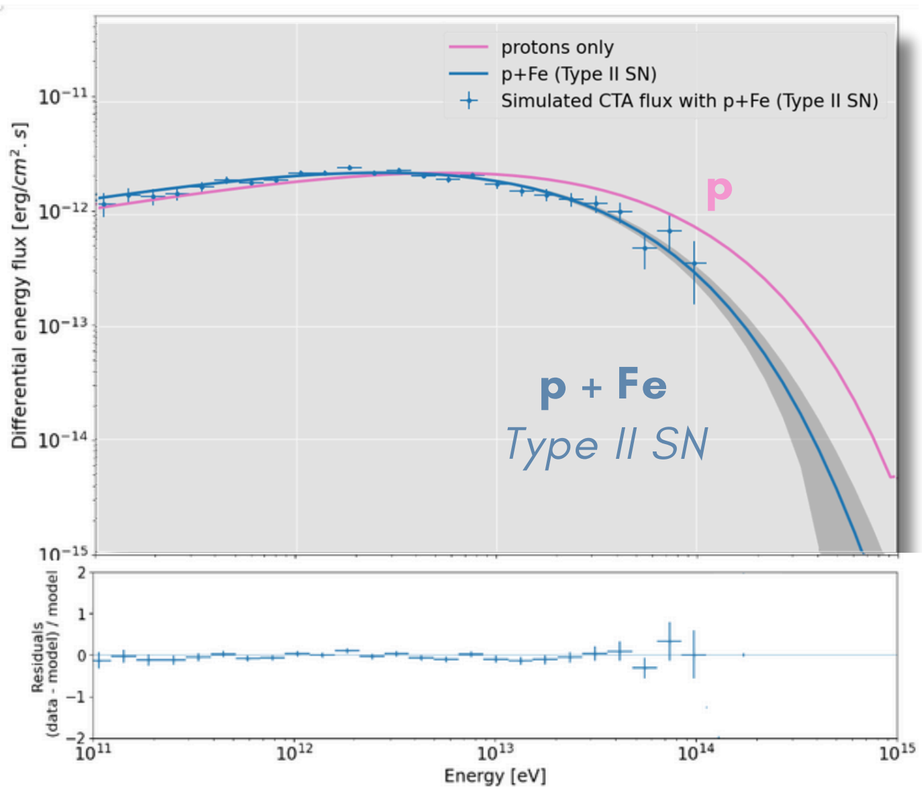
III - CAN CTAO DETECT CRs FROM SNRs?

CTAO simulations of **RX J1713.7-3946**



ΔTS = 188 ✓

CTAO simulations of **HAWC J2227+610**



ΔTS = 88 ✓

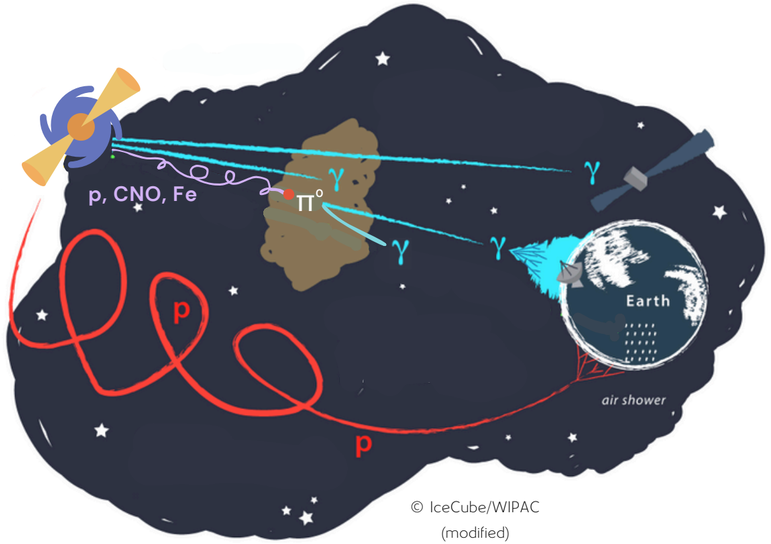
CONCLUSION

Why study CRs with CTAO?

CTAO offers indirect means of **pinpointing the CR source** using gamma-rays. Actually, charged CRs are deviated by Galactic magnetic fields and lose the knowledge of their original direction.

What will CTAO bring to the knowledge of CRs?

CTAO will increase the sensitivity to the spectral shape of γ-rays. In addition to a MWL analysis, this will allow us to **distinguish protons from heavy CRs and thus investigate the origin of very high energy CRs**.



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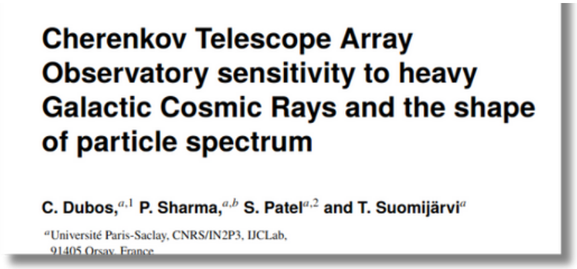
(modified)

Where can we find this work?

JCAP, Dubos, Sharma, Patel, and Suomijärvi, February 2025 (DOI: 10.1088/1475-7516/2025/02/078)

SCAN ME


Cherenkov Telescope Array Observatory sensitivity to heavy Galactic Cosmic Rays and the shape of particle spectrum

C. Dubos,[a,1] P. Sharma,[a,b] S. Patel[a,2] and T. Suomijärvi[a]

[a]Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

CTAO could investigate the **origin of the particle distribution shape**, which may result from **heavy nuclei** or various **acceleration scenarios**.

WHAT ABOUT THE OTHER PEVATRON CANDIDATES?

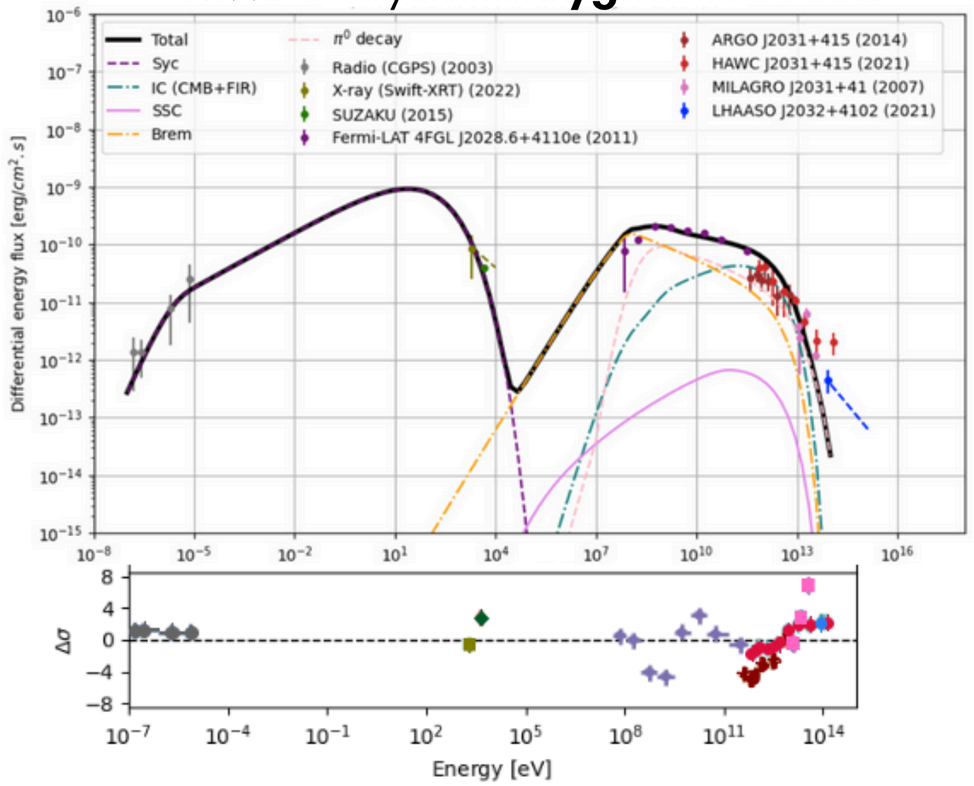
CRs accelerated by Galactic sources? PeVatrons

PeVatron candidates:

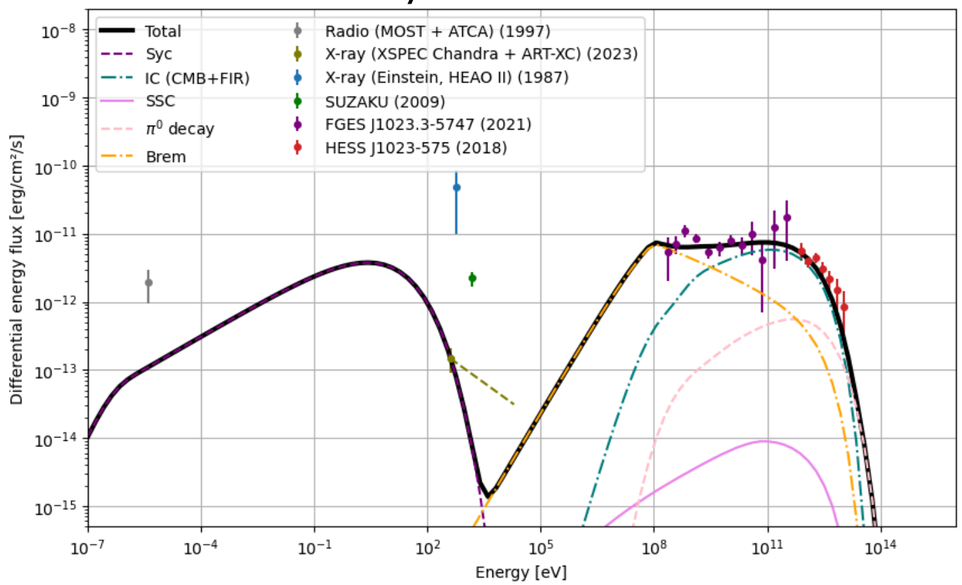
Supernova Remnant

Stellar Cluster

MWL analysis of **Cygnus Cocoon**



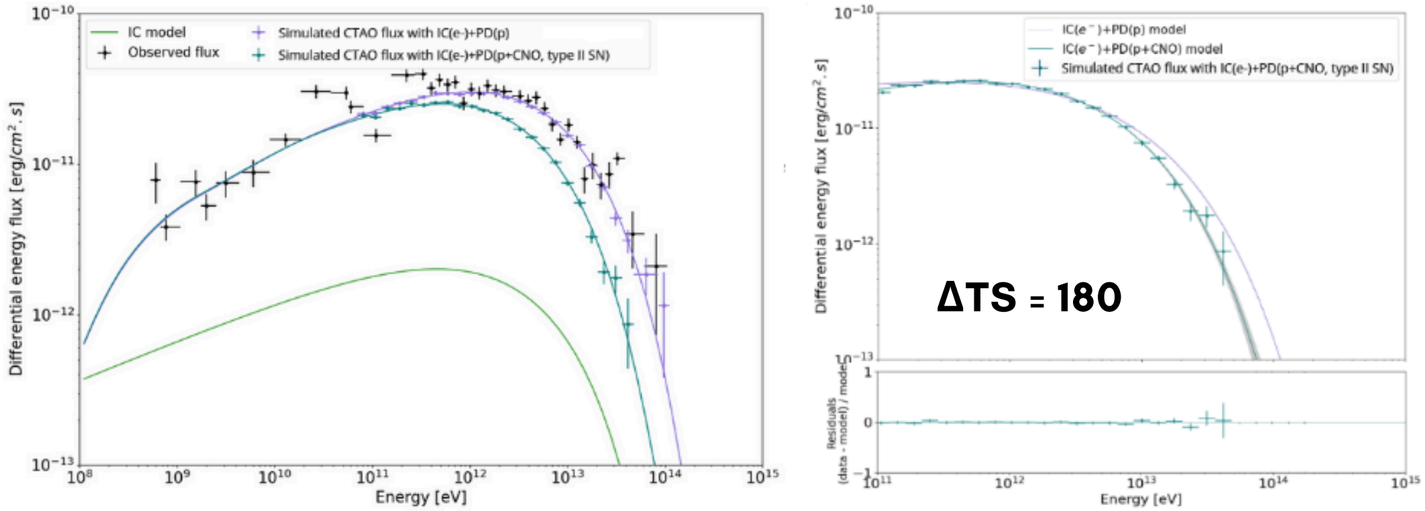
MWL analysis of **Westerlund II**



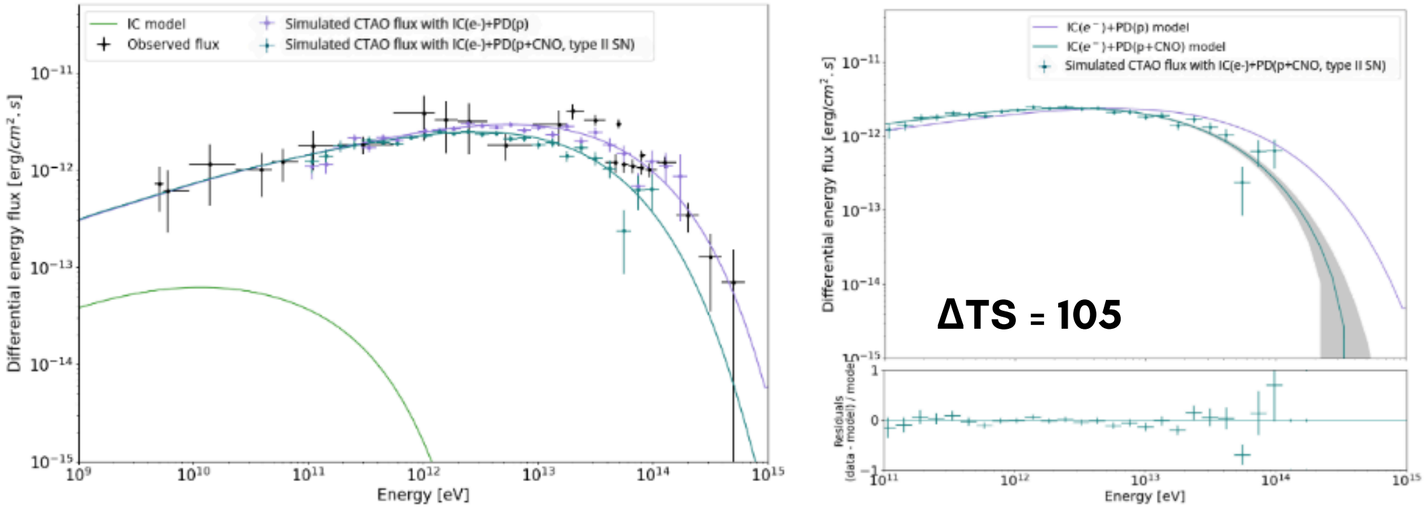
PRELIMINARY RESULTS

APPENDIX CONTRIBUTION OF ELECTRONS THROUGH THE INVERSE COMPTON PROCESS

RX J1713.7-3946

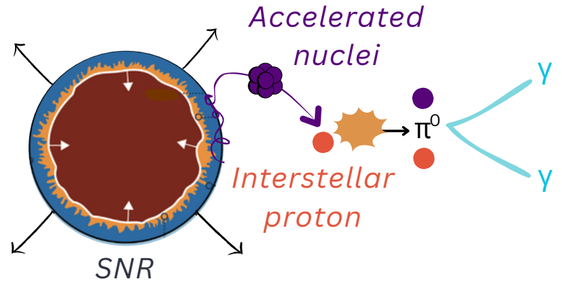


HAWC J2227+610



HADRONIC PROCESS FOR GAMMA-RAYS

proton-proton interaction -
Neutral pion decay process



LEPTONIC PROCESS FOR GAMMA-RAYS

Synchrotron
Bremsstrahlung
Inverse Compton
processes