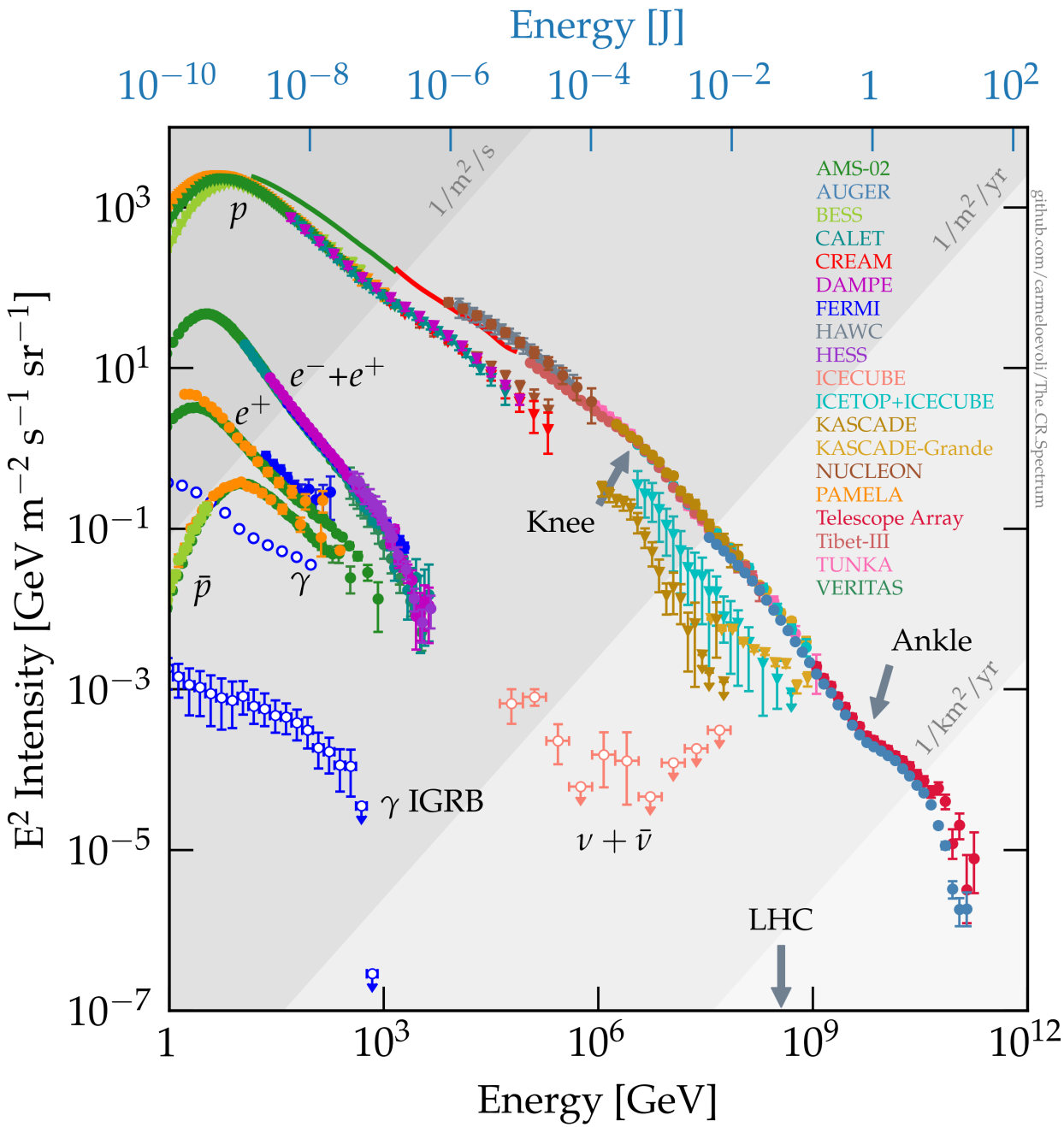
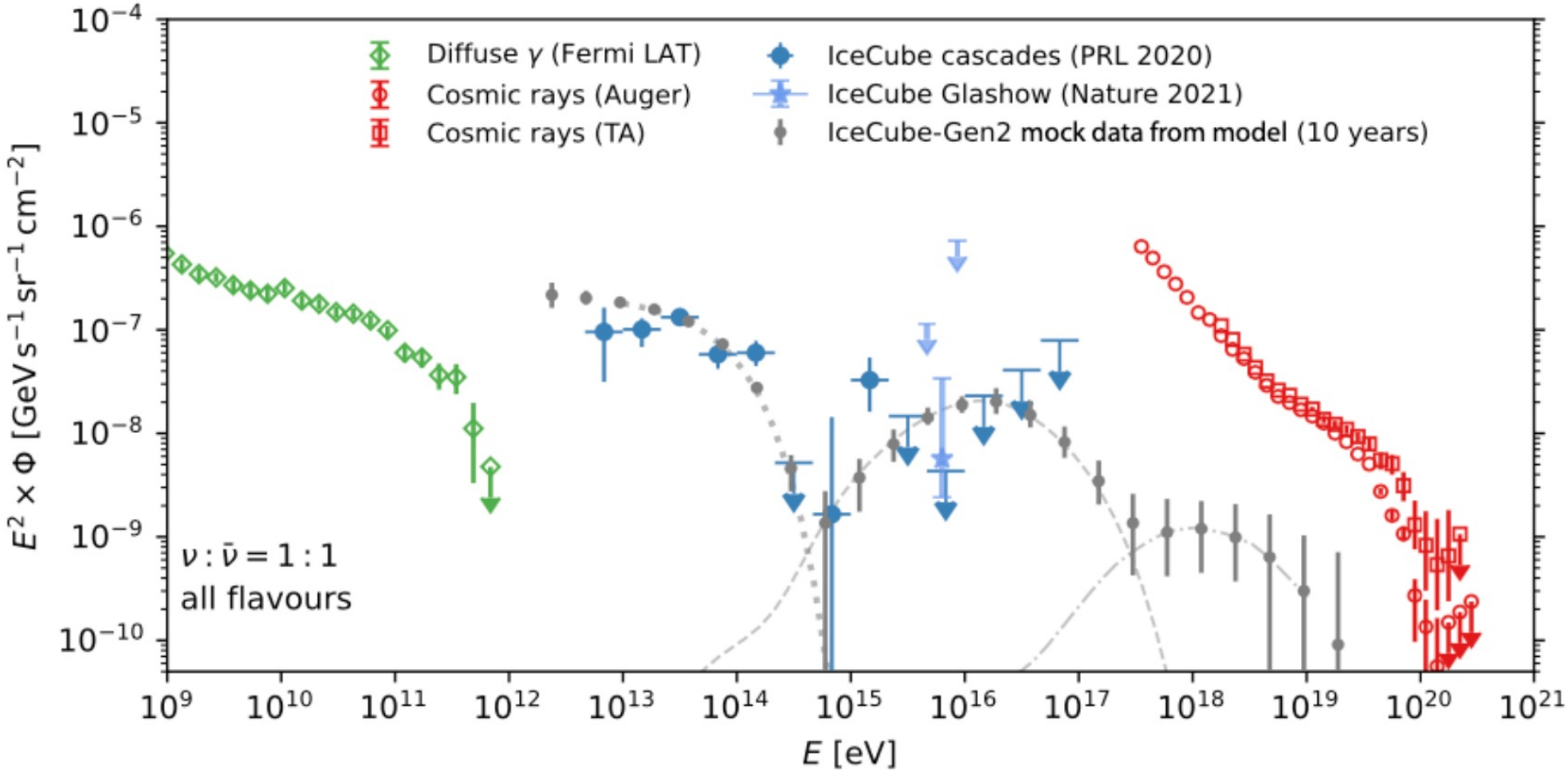
General Introduction on HE activities Theory

Roberto Aloisio (GSSI) on behalf of the HE-TH group

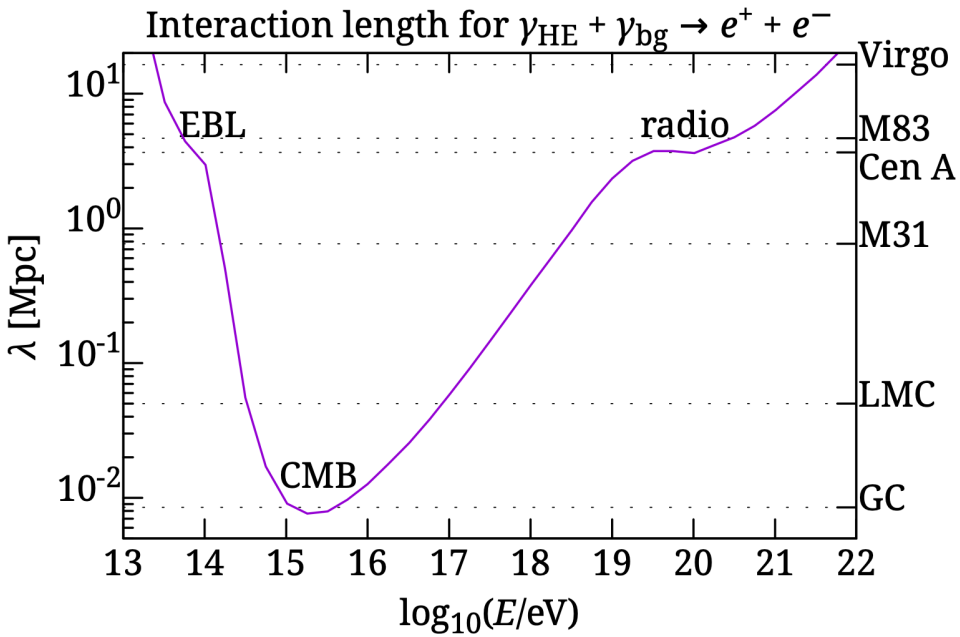
The high-energy messengers

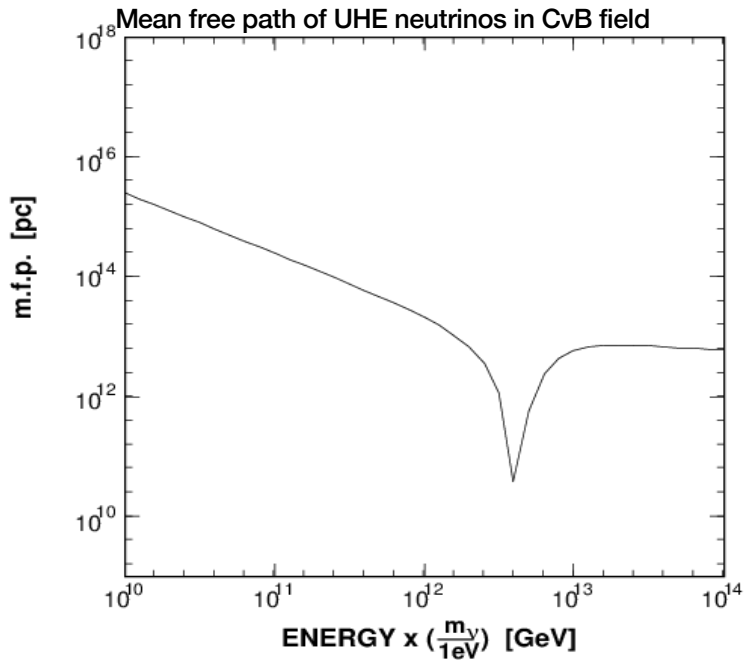


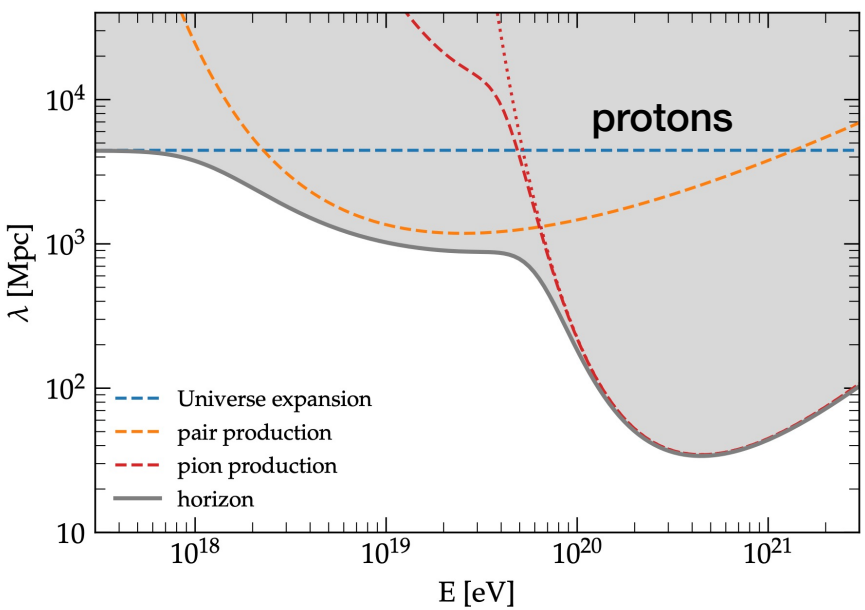


arXiv:2203.08096

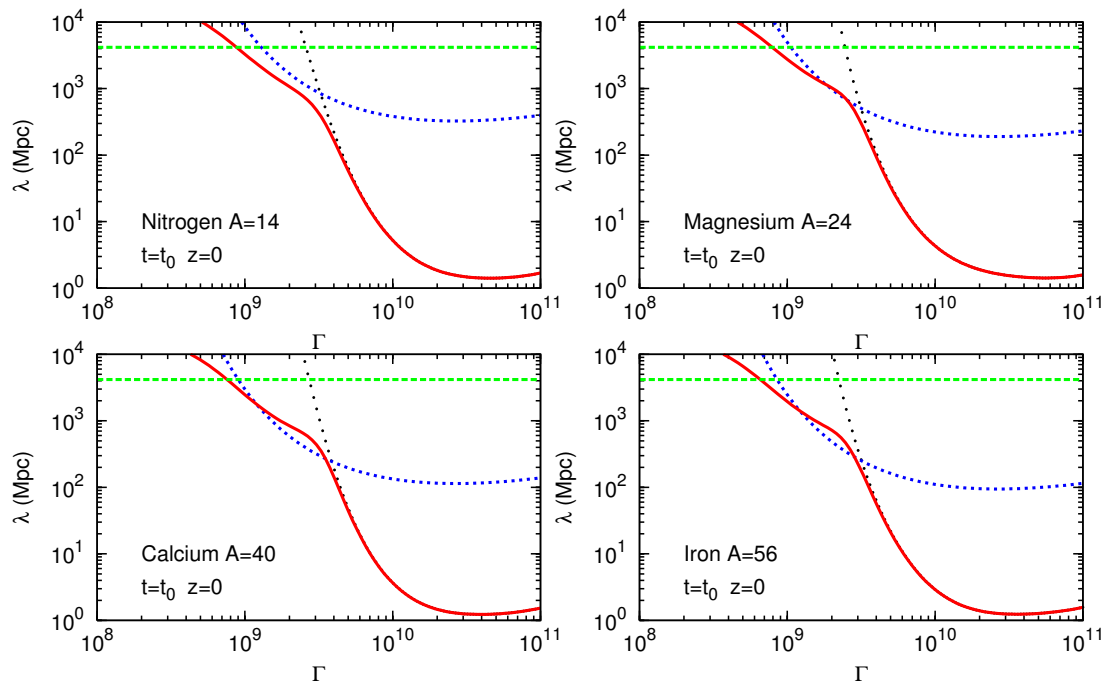
A tomography of the high-energy universe



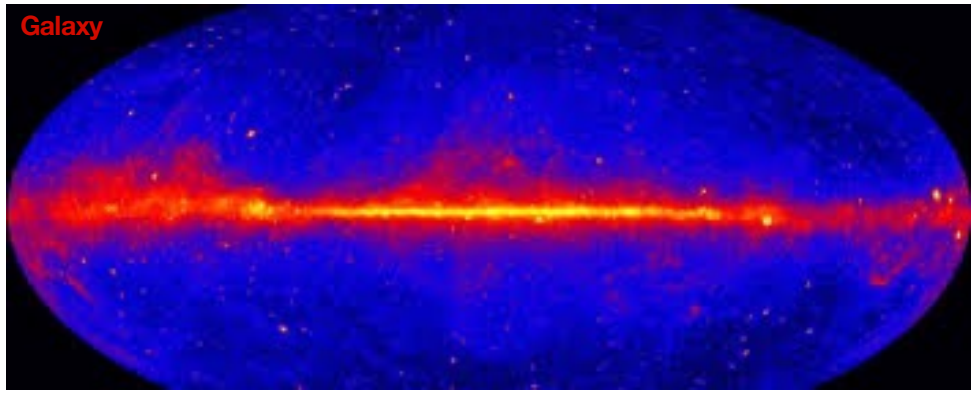


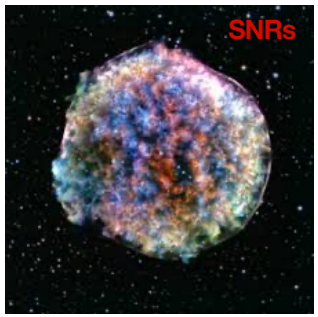


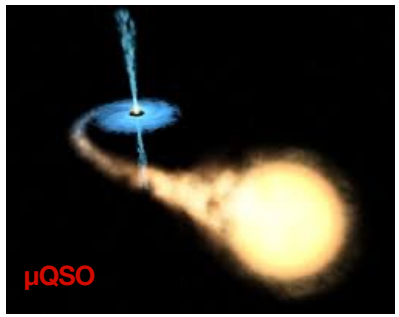
nuclei



Non thermal particles







ALL THESE EMISSIONS REQUIRE ACCELERATION MECHANISMS TO BE AT WORK AND TRANSPORT MECHANISMS ACROSS DIFFERENT MEDIA.

Theoretical High Energy Astrophysics

The understanding of the universe on large scales requires the investigation of the microphysics, and in turn the big scales tell us about microphysics (D.N. Schramm).

Whether we talk about cosmic rays, gamma rays or neutrinos, of non-thermal phenomena in astrophysical systems, we observe phenomena on very large scales, whose interpretation lies in the microscopic scales of either particle physics or plasma physics, or both. Such microphysics is basically the same despite the variety of manifestations on large scales.

- ✓ **THEORETICAL STUDY OF HIGH ENERGY ASTROPHYSICS FOCUSES ON NATURAL PHENOMENA WHERE LARGE MICROSCOPIC AND MACROSCOPIC ENERGIES ARE OFTEN INVOLVED.**
- ✓ **MULTI-FREQUENCY AND MULTI-MESSENGER STUDIES ARE PIVOTAL TO THIS FIELD.**
- ✓ **IN MOST THEORETICAL ASTROPARTICLE PHYSICS, IT IS OFTEN NECESSARY TO ADOPT A DOUBLE APPROACH: PHENOMENOLOGICAL AND FUNDAMENTALIST, AS PHENOMENOLOGY IT IS ALWAYS THE GUIDLINE TO DEVELOP NEW FUNDAMENTAL APPROACHES.**
- ✓ **THE GOAL IS OF GETTING TO THE BOTTOM OF THINGS, TO A THEORY BASED ON FUNDAMENTAL CONCEPTS, NO MATTER IF THEY ARE ROOTED IN PARTICLE PHYSICS, PLASMA PHYSICS, ASTROPHYSICS AND COSMOLOGY.**

What's our research about?

To answer fundamental questions!

What is the nature of complex astrophysical systems?

How astrophysical plasma can accelerate particles?

What is the nature of turbulence? And its dynamical evolution?

How is energy transferred in magnetic reconnection?

What can be learned about Astrophysical objects dynamics?

What can be learned about the early universe?

…

What is the nature of elementary matter?

Why was there so much more ordinary matter than antimatter?

What is the particle nature of Dark Matter?

What can be learned on the SM at extreme conditions?

Is there new particles beyond the Standard Model?

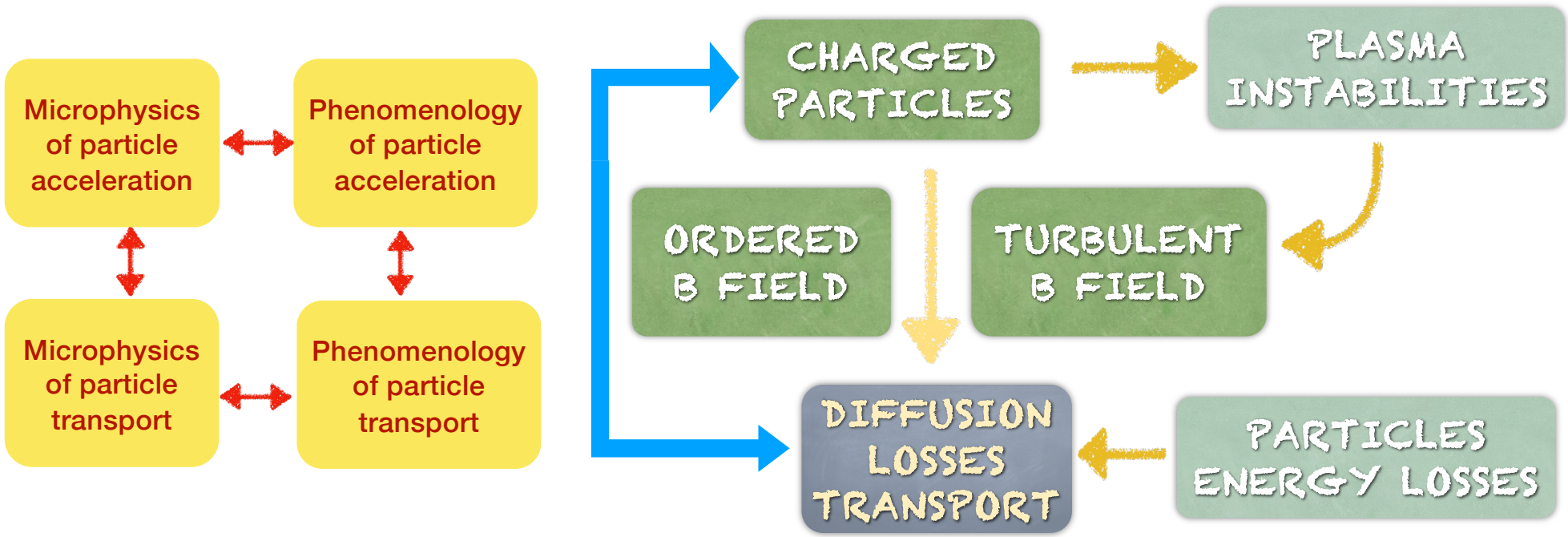
Is there any new (or extended) symmetry in Nature (BSM physics)?

…

A paradigmatic instance

Acceleration and propagation of Cosmic Rays

- ✓ Ensemble of non-thermal charged particles that move in a (partially ionized) plasma under the action of external electric and magnetic fields.
- ✓ Both non-thermal particles and plasma particles contribute electric charges, also producing E and B fields and create electric currents, all particles feel what all others are doing.
- ✓ Non-thermal particles may interact with plasma particles and/or radiation fields, reducing their energy and producing secondary (observable) particles.
- ✓ Usually even non-thermal particles were, at some point, particles of the plasma. How did they get accelerated and ejected out of the source? How did they traveled reaching Earth detectors? Is there any secondary (detectable) emission produced?



The HE theory group at GSSI-LNGS-UAQ

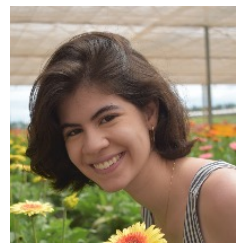








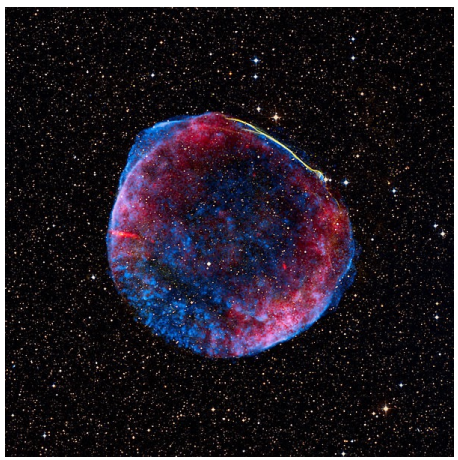


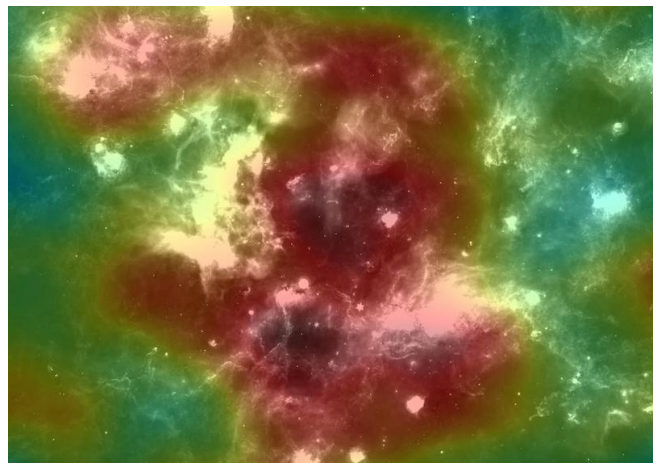


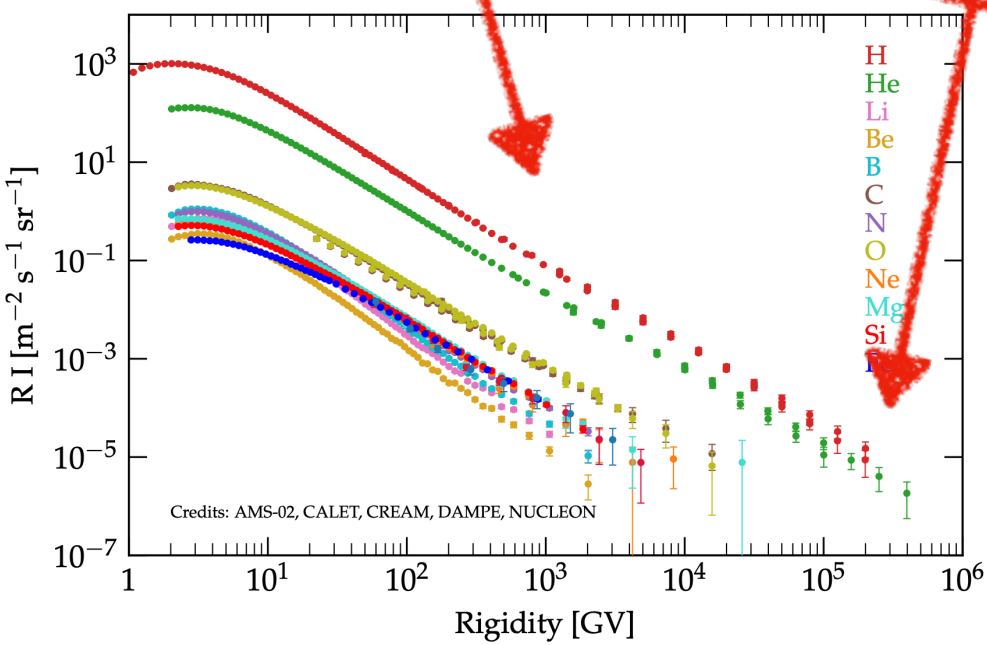


The activity of the group is conducted in close collaboration with experimental groups, also through the direct participation to experimental collaborations such as Auger, NUSES and PBR.

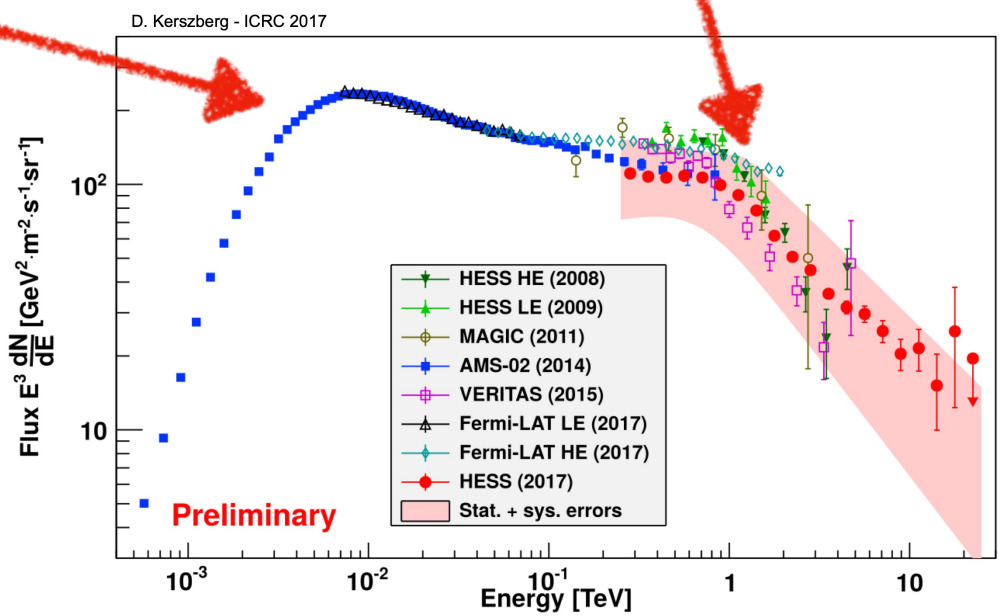
What are cosmic ray factories in our Galaxy?





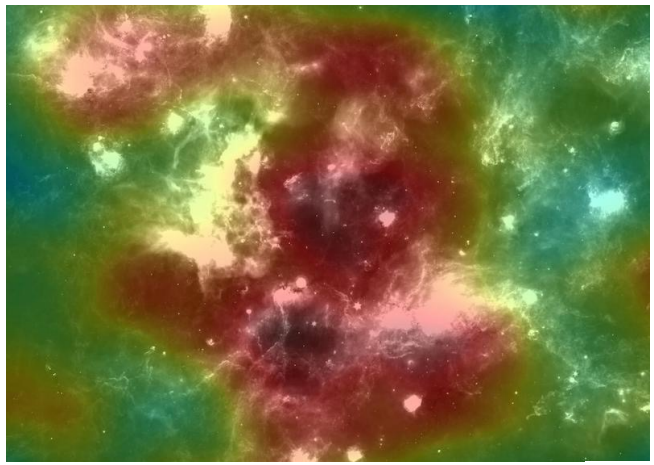


Evoli, Aloisio, Blasi, PRD, 2019



Evoli, Amato, Blasi, Aloisio, PRD, 2021

What are cosmic ray factories in our Galaxy?



Particle acceleration in winds of star clusters

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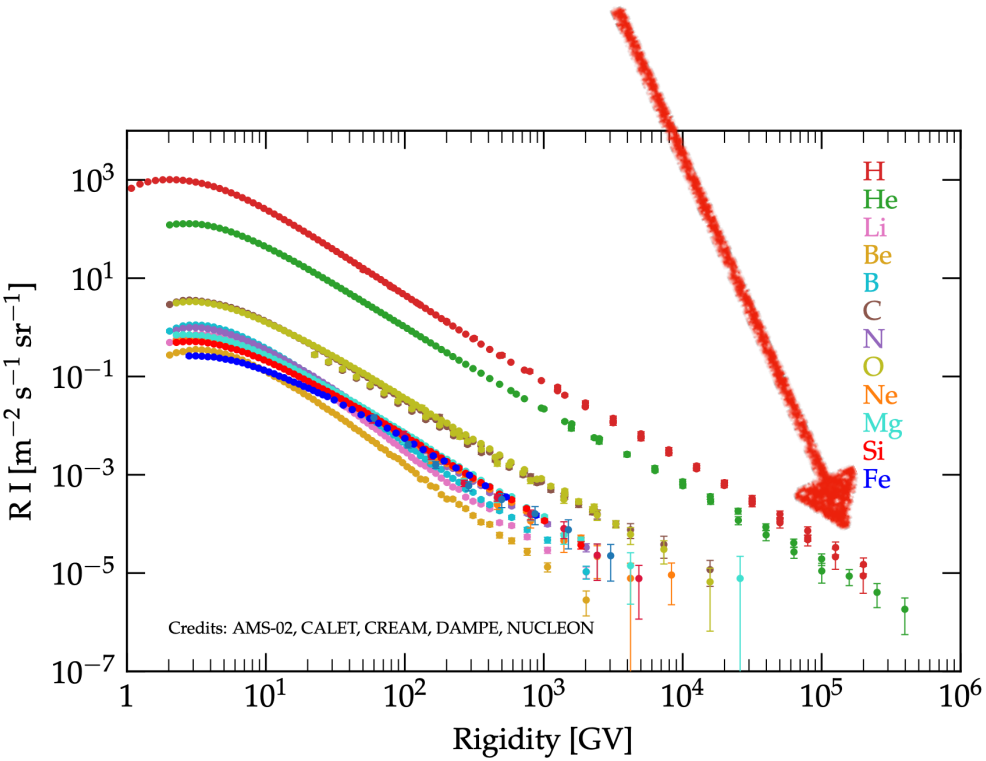
[1] *INAF/Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 5 - 50125 Firenze, Italy*
[2] *Gran Sasso Science Institute (INFN), Viale F. Crispi 7 - 67100 L' Aquila, Italy*
[3] *INFN-Laboratori Nazionali del Gran Sasso, Via G. Acitelli 22, Assergi (AQ), Italy*
[4] *Niels Bohr International Academy, Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark*

Accepted XXX. Received YYY; in original form ZZZ



ABSTRACT

The origin of cosmic rays in our Galaxy remains a subject of active debate. While supernova remnant shocks are often invoked as the sites of acceleration, it is now widely accepted that the difficulties of such sources in reaching PeV energies are daunting and it seems likely that only a subclass of rare remnants can satisfy the necessary conditions. Moreover the spectra of cosmic rays escaping the remnants have a complex shape that is not obviously the same as the spectra observed at the Earth. Here we investigate the process of particle acceleration at the termination shock that develops in the bubble excavated by star clusters' winds in the interstellar medium. While the main limitation to the maximum energy in supernova remnants comes from the need for effective wave excitation upstream so as to confine particles in the near-shock region and speed up the acceleration process, at the termination shock of star clusters the confinement of particles upstream in guaranteed by the geometry of the problem. We develop a theory of diffusive shock acceleration at such shock and we find that the maximum energy may reach the PeV region for powerful clusters in the high end of the luminosity tail for these sources. A crucial role in this problem is played by the dissipation of energy in the wind to magnetic perturbations. Under reasonable conditions the spectrum of the accelerated particles has a power law shape with a slope $4 \div 4.3$, in agreement with what is required based upon standard models of cosmic ray transport in the Galaxy.

Key words: cosmic rays – star clusters – acceleration of particles – shock waves

and in other Galaxies?

Astrophysics > High Energy Astrophysical Phenomena

[Submitted on 18 Sep 2022]

Testing hadronic and photo-hadronic interactions as responsible for UHECR and neutrino fluxes from Starburst Galaxies

Antonio Condorelli, Denise Boncioli, Enrico Peretti, Sergio Petrera

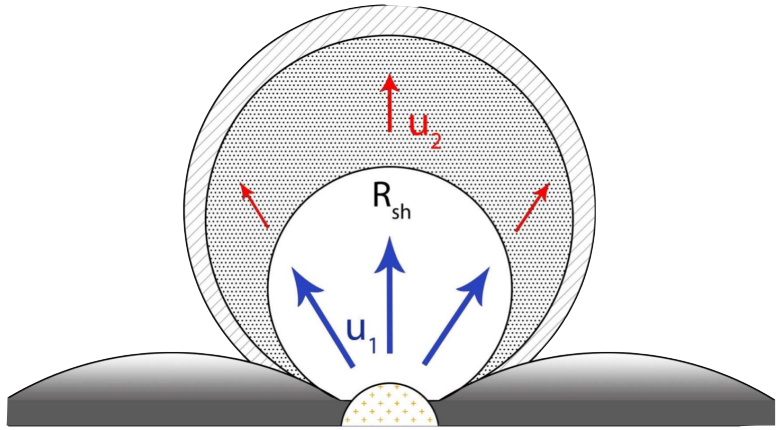
Astrophysics > High Energy Astrophysical Phenomena

[Submitted on 22 Apr 2021 (v1), last revised 13 Feb 2022 (this version, v2)]

Particle acceleration and multimessenger emission from starburst-driven galactic winds

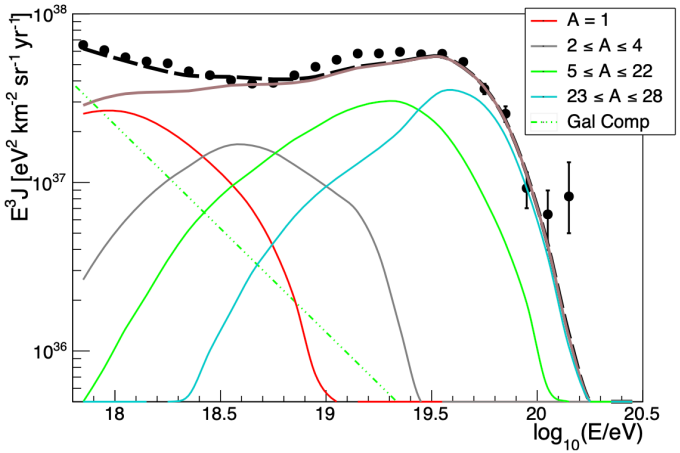
Enrico Peretti, Giovanni Morlino, Pasquale Blasi, Pierre Cristofari

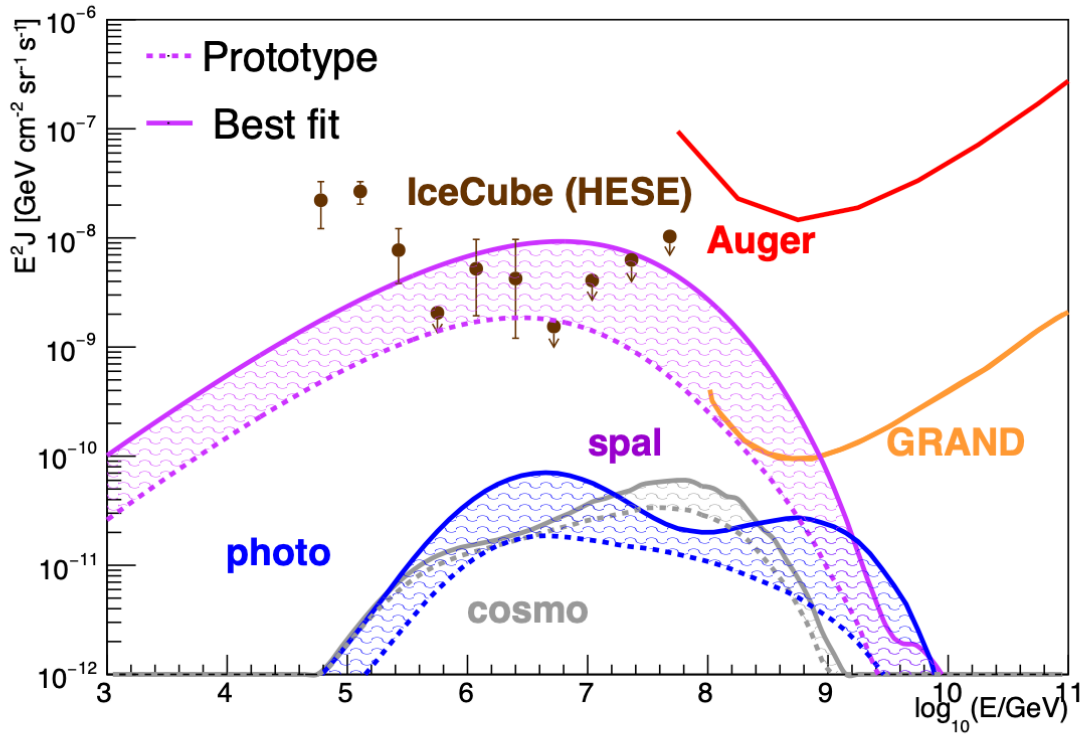
Now in Paris



Now in CPH

and in other Galaxies?





Now in Paris

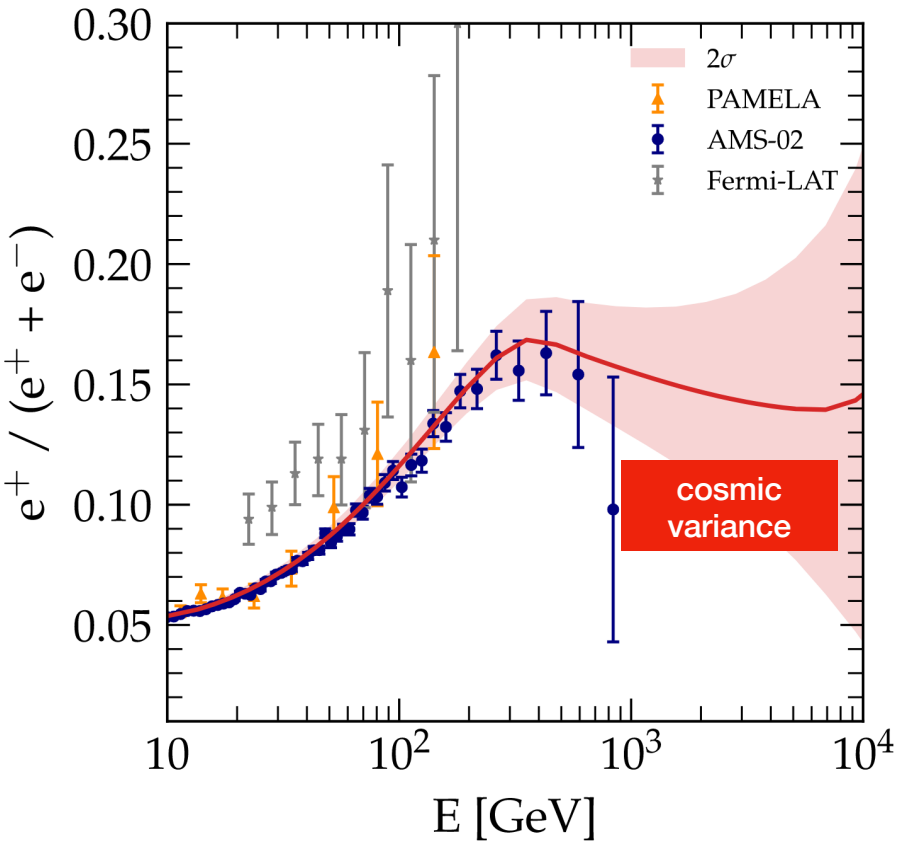
multi-messenger constraints on UHECR sources!

Condorelli, Peretti, Boncioli, Petrera, 2023

Now in CPH

On the origin of anti-matter

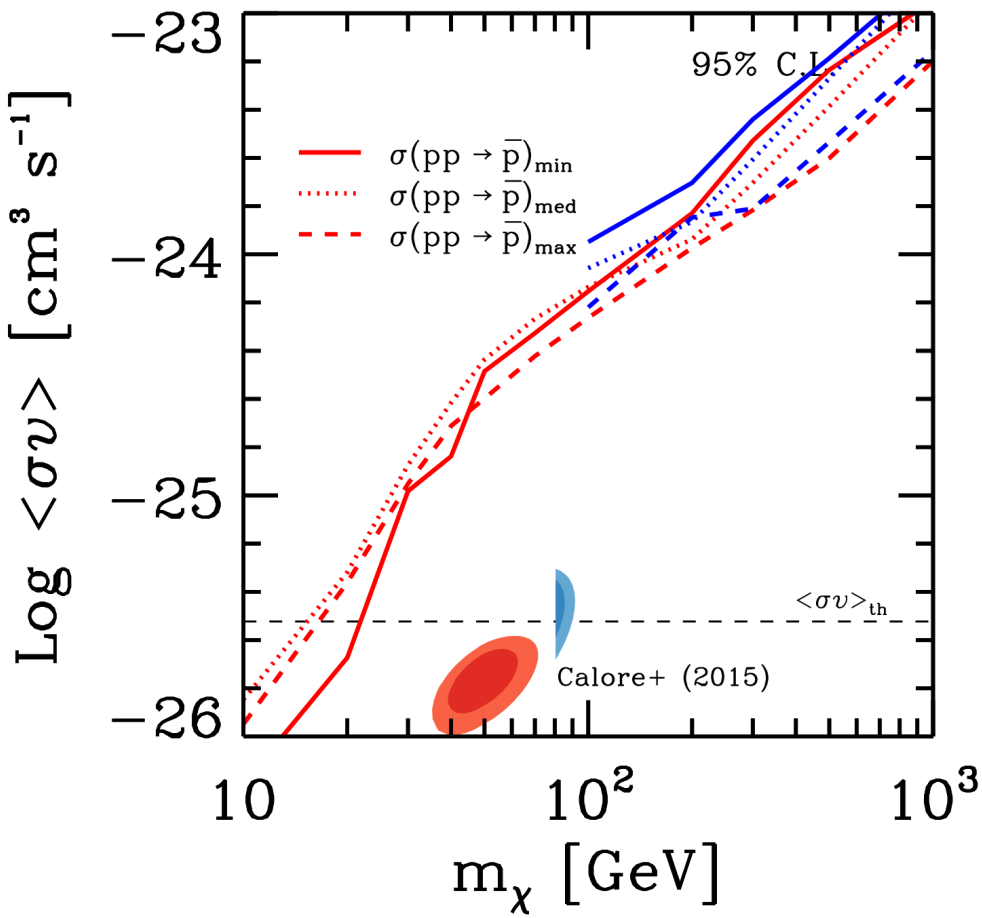
The positron excess as produced by the pair emission of galactic Pulsars



(poster by Lioni-Moana)

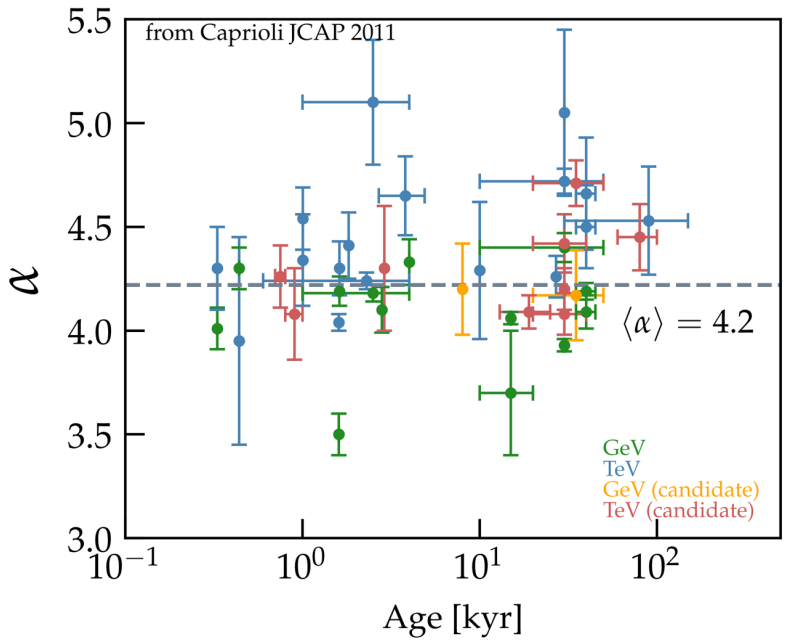
Evoli et al., PRD, 2021

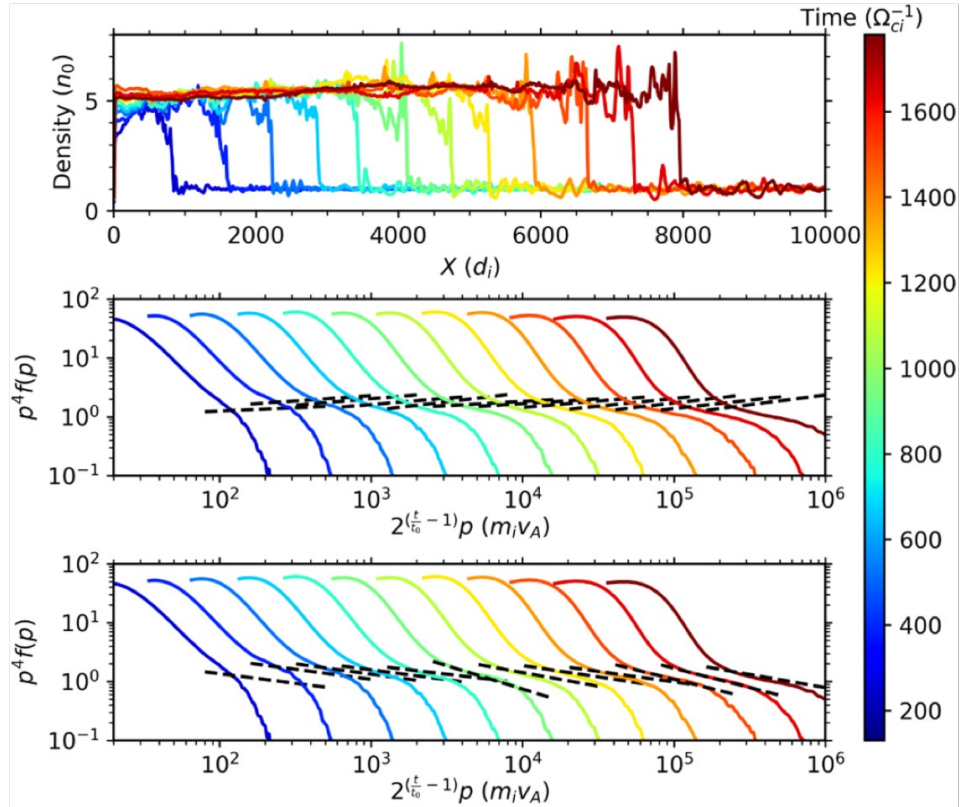
Limits on Dark Matter WIMPs set by antiprotons fluxes



Evoli et al., JCAP, 2015

Understanding acceleration





New ideas in non-linear DSA theory:

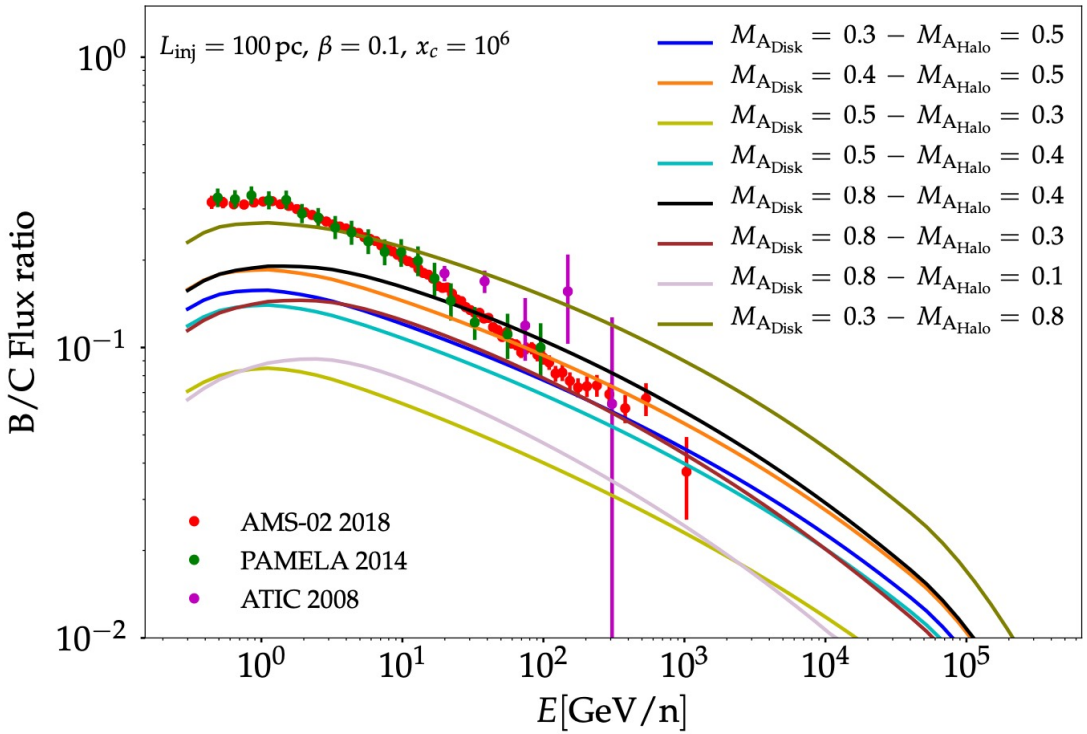
Amplified waves advected downstream of the shock lead to higher Alfven speed
-> hence smaller return probability of downstream

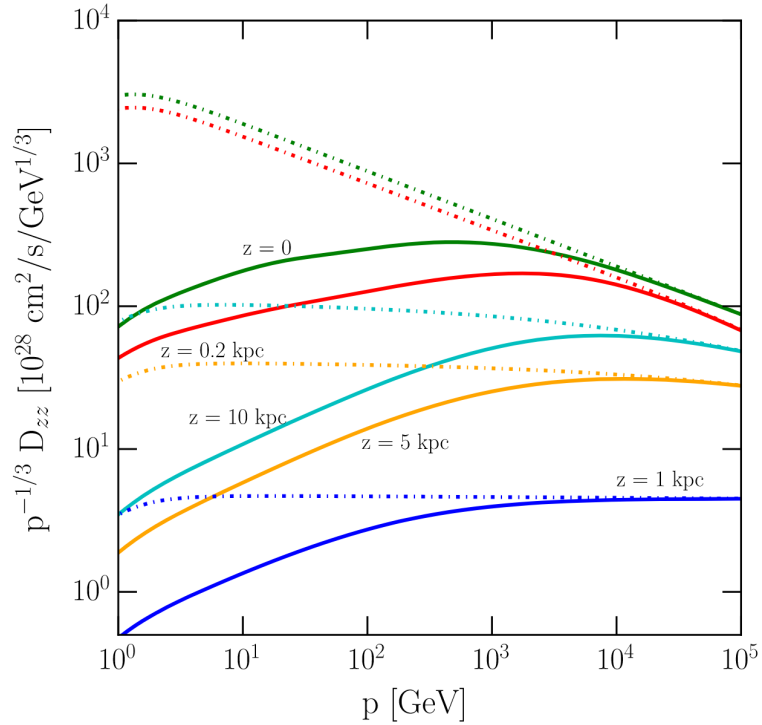
This phenomenon leads to a steeper spectrum of accelerated particles, in general dependent upon the

Very steep spectrum for very fast shocks!

Caprioli, Haggerty, Blasi, ApJ, 2020

Understanding Galactic transport





Which are the relevant processes responsible for CR confinement in the Galaxy?

Origin of the turbulence: external cascade or self-generated?

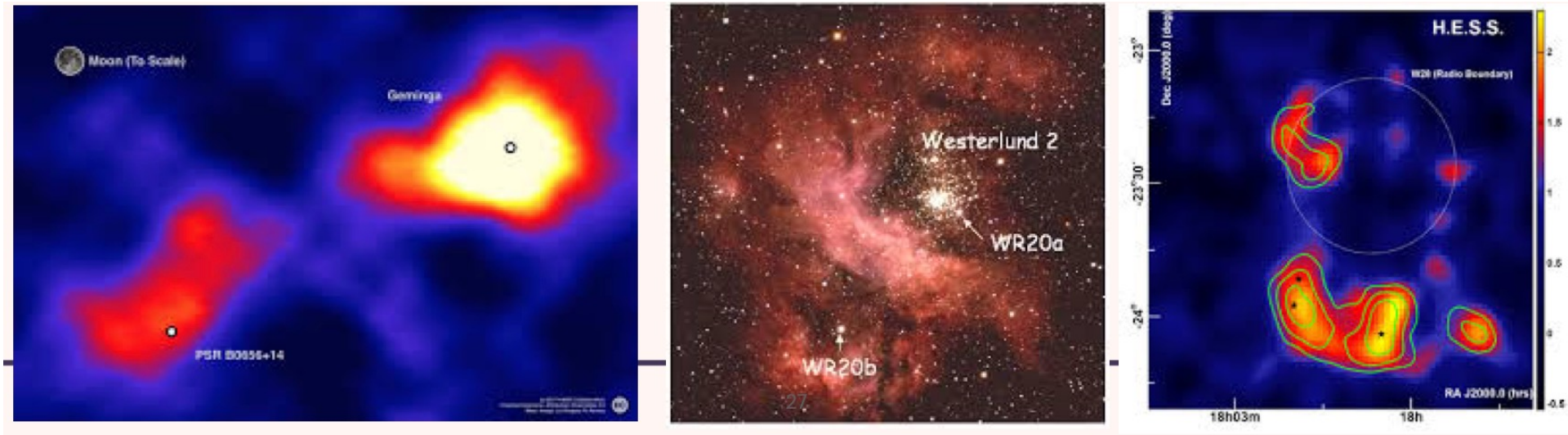
Turbulence model: Alfvenic or other MHD modes?

Blasi, Amato, Serpico, PRL, 2012

Evoli, Blasi, Morlino, Aloisio, PRL, 2018

Fornieri et al., MNRAS, 2021

The cosmic ray self-control: a novel story!



reduced diffusivity around sources now observed in several objects: perhaps is due to cosmic rays self-confinement!

through kinetic instabilities or a combination of streaming and hydrodynamics

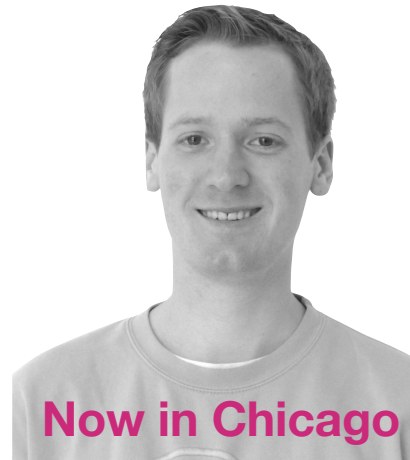
several effects still to be investigated!

(see poster by Alessandro)

D'Angelo, Amato, Blasi, MNRAS, 2015, 2016

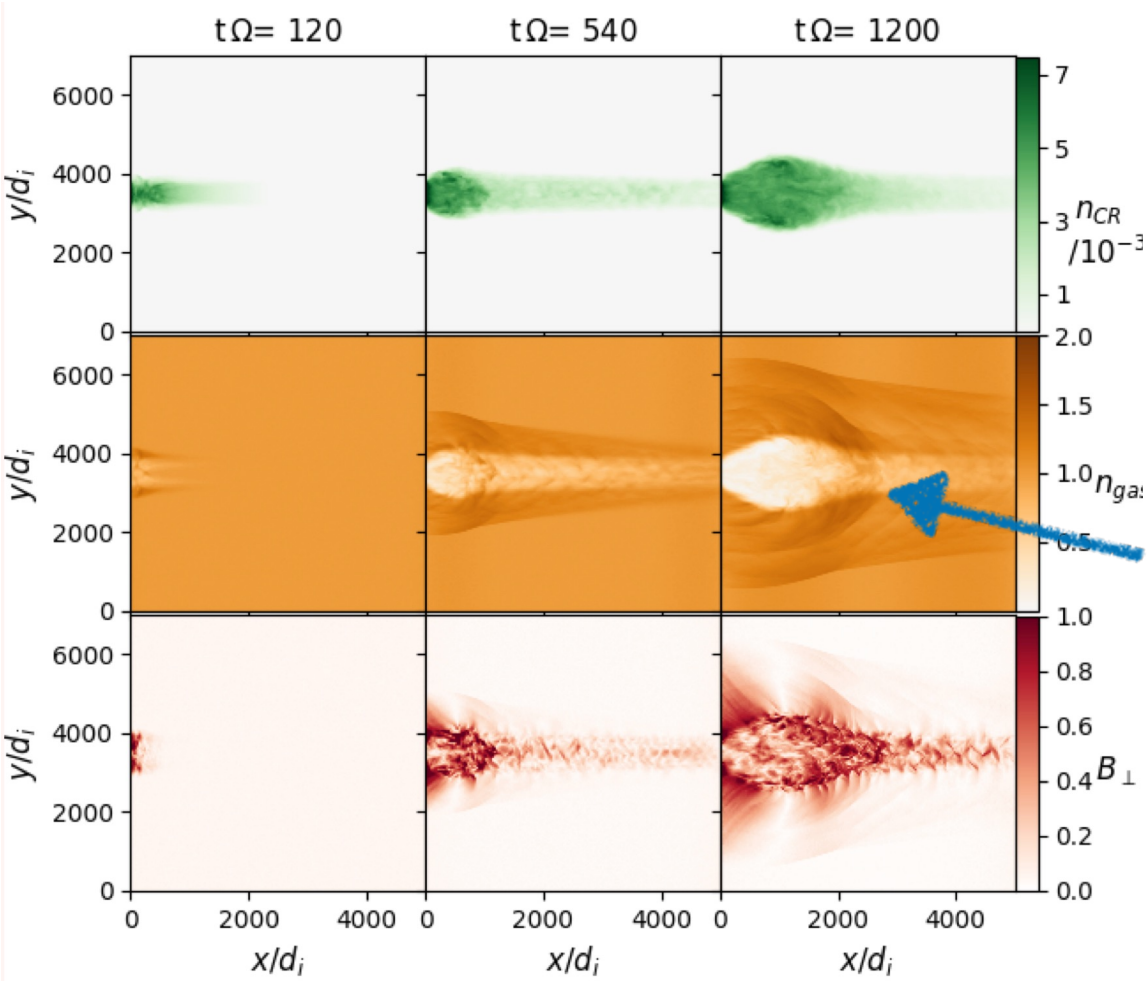
Schroer, Blasi, et al., ApJ, 2021

Evoli, Linden, Morlino, PRD, 2015, 2016



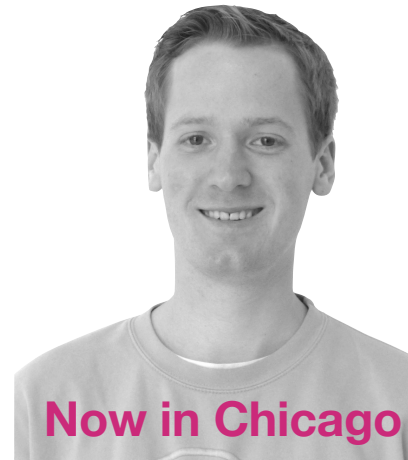
Now in Chicago

The cosmic ray self-control: a novel story!

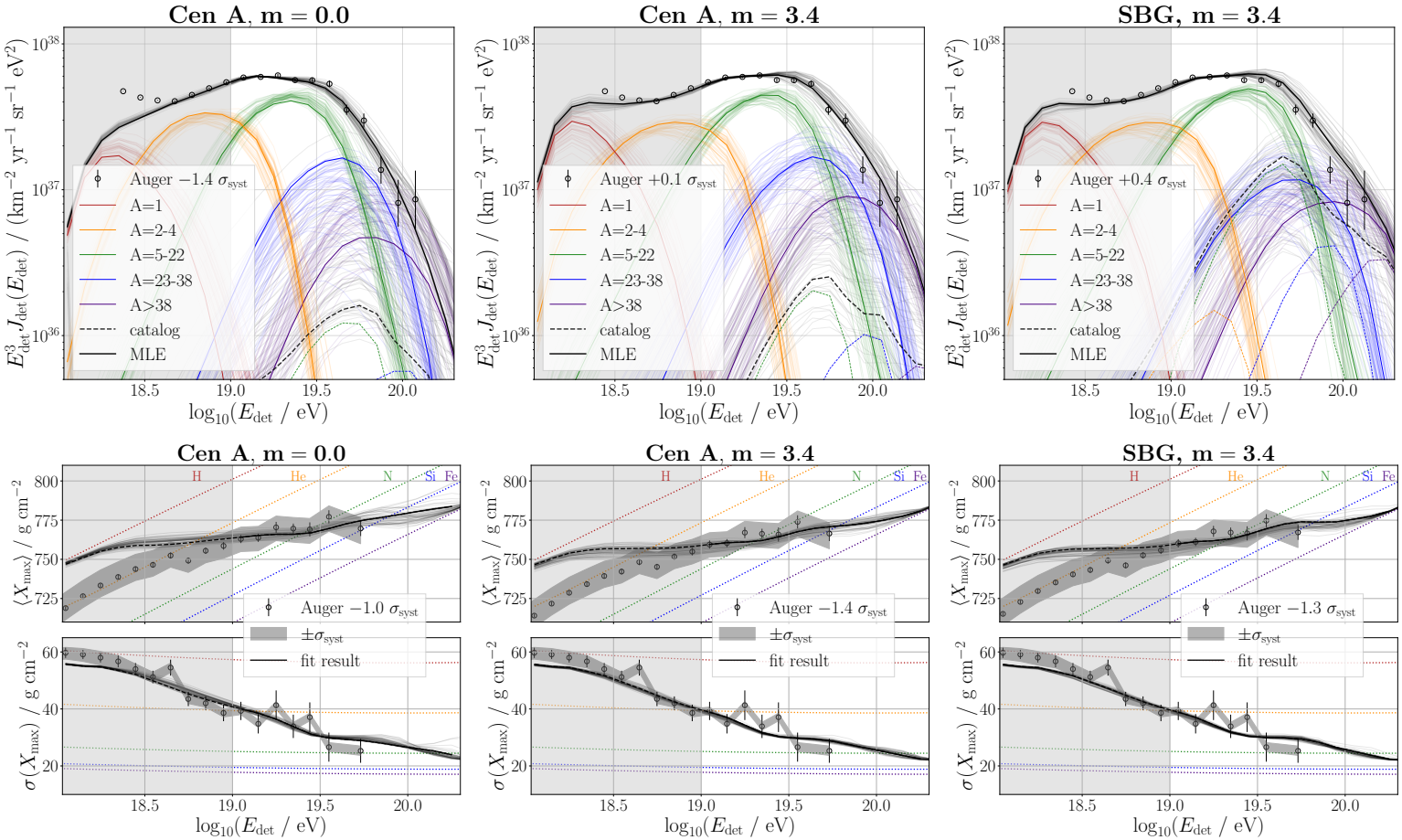


The excitation of the instability leads to strong particle scattering, which in turn increases CR density near the source

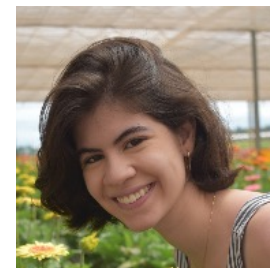
The pressure gradient that develops creates a force that leads to the inflation of a bubble around the source



Ultra High Energy Cosmic Rays

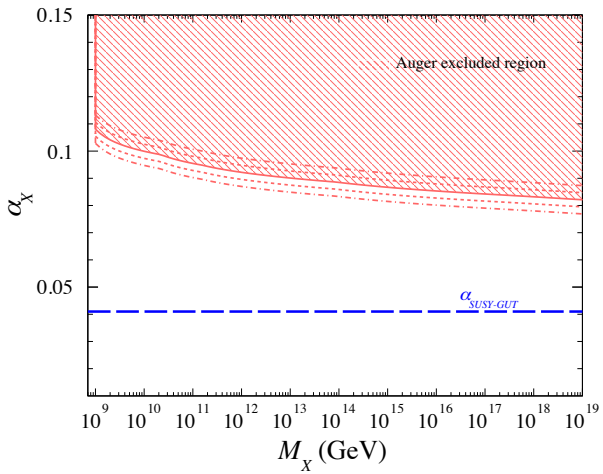


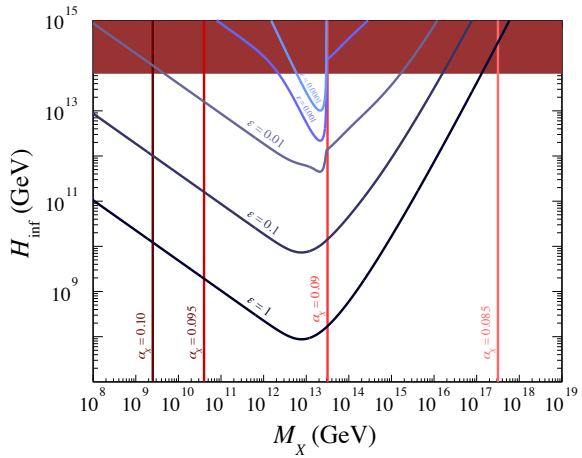
Constraining models for the origin of ultra-high-energy cosmic rays with a novel combined analysis of arrival directions, spectrum, and composition data measured at the Pierre Auger Observatory (poster by Luciana and the UnivAQ Auger group).

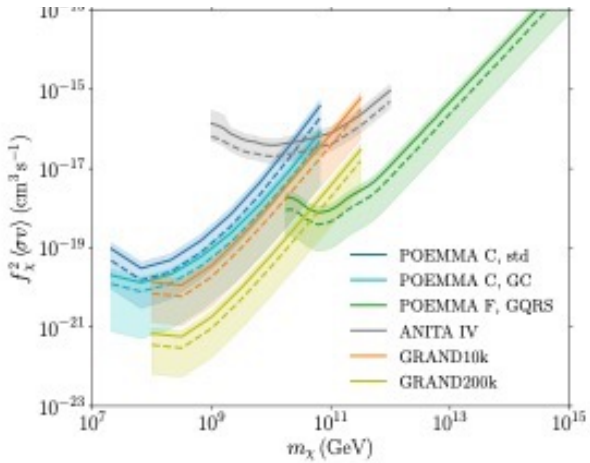


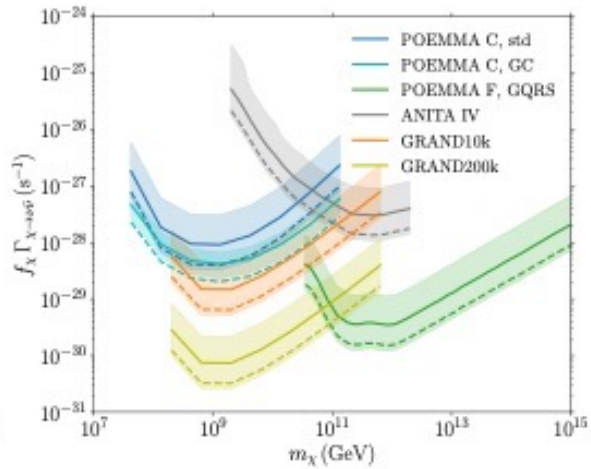
Auger Coll. JCAP, 2024

Super Heavy Dark Matter









Cosmological implications of photon-flux upper limits at ultra-high energies in scenarios of Super Heavy Dark Matter (SHDM).

Limits to gauge coupling in the dark sector set by the non-observation of instanton-induced decay of SHDM.

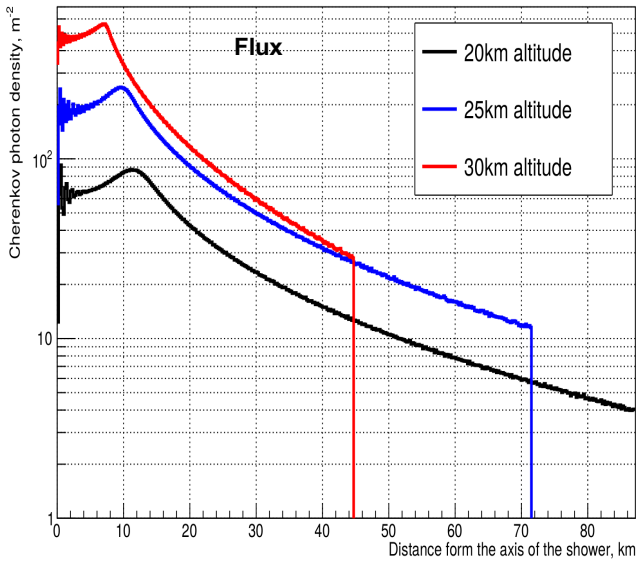
Indirect DM searches at future high energy neutrino detectors.

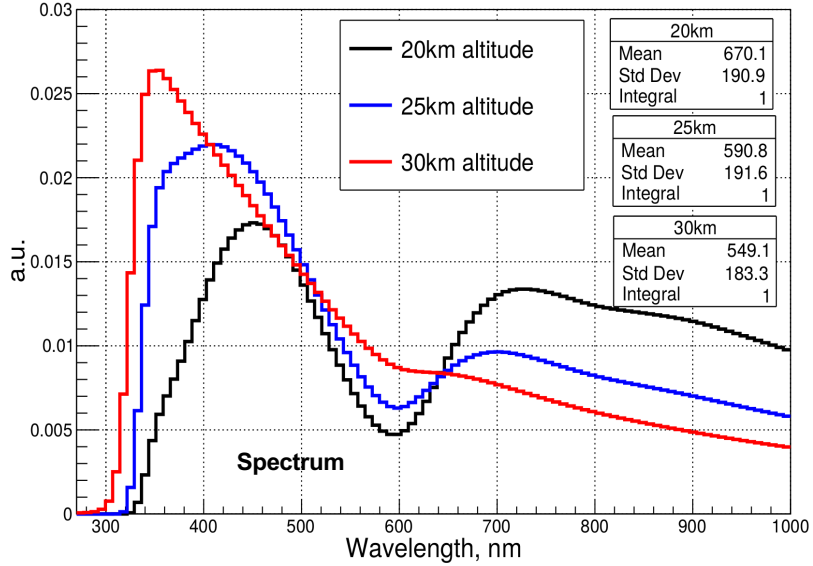
Auger Coll. PRD, 2022

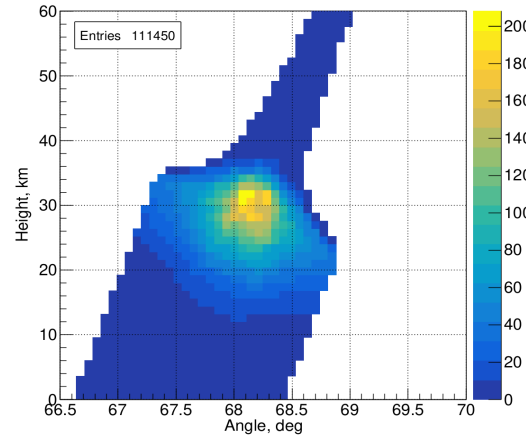
Auger Coll. PRL, 2022

Guépin, Aloisio, Anchordoqui, Cummings, Krizmanic, Olinto, Reno, Venters, PRD, 2021

Hunting for neutrinos at the highest energies







Earth skimming neutrinos phenomenology

A novel observation technique of HE-UHE neutrinos from space and sub-orbital altitudes

An instance of a phenomenological study that leads to new experimental enterprises (NUSES-Terzina, PBR, see talk by Adriano and the poster by Giulio).

Cummings, Aloisio, Krizmanic, PRD, 2021

Cummings, Aloisio, Eser, Krizmanic, PRD, 2021

HE-AP The Road Ahead

Discovering where high-energy cosmic rays come from has been a ***grail of physics*** *since their discovery.*

Suspected sources include some of the ***most violent and energetic phenomena in the universe****, probing regimes far more powerful than any on Earth.*

Many ***new experimental and observational facilities*** *are starting. An unprecedent large amount of new data foreseen in the forthcoming years: no lack of rich science cases…*

The recent detection of GW from compact sources naturally connects this field of research with HE Astrophysics in a genuine ***multi-messenger approach****…*

*…****the discovery potential*** *in the next decades is enormous on both experimental and theoretical sides.*

Here lies the uniqueness of doing a PhD in HE-TH in L'Aquila!

GRAN SASSO SCIENCE INSTITUTE

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

UNIVERSITÀ DEGLI STUDI DELL'AQUILA