COSMIC RADIATION

Observing the sky with different messengers
Photons, Neutrinos, Cosmic Rays, Gravitational Waves
Great extension of our power to study the Universe

Scientific Motivations

- Study some of the most fascinating objects and events in Nature: Neutron stars, Pulsars, Black Holes, …
- Dark Matter: discovered by astronomical means, can be investigated with the tools of astroparticle physics
- Finding the counterparts of the Gravitational Wave emitters
- Investigate ”extreme environments” as laboratories to test the fundamental laws of Nature

Outlook

- Solar neutrinos, supernova neutrinos’, geo-neutrinos
- Atmospheric and cosmic neutrinos
- Gamma astronomy, from space and from the ground
- Precision measurements of cosmic rays from space
- Cosmic rays at the highest energy (E ~10^{19} eV)

Learning fundamental physics in the laboratory & observing the sky
Enrico Fermi: nuclear physics, accelerators & cosmic rays
Edoardo Amaldi: founder of CERN & pioneer of CR and GW search

CHARGED COSMIC RAYS

Direct measurements (space based)

- Science Cases - sources, propagation, anti-matter, DM, study of environment for manned flight
- Observables - individual elements energy spectra and related features; anisotropies
- Pros : good systematics, Cons: low acceptance (reduced energy reach)

→ *next challenge: extend precise CR spectroscopy towards the knee: (DAMPE up to hundreds TeV, … HERD up to few PeV)*

→ *next to next challenge: extend anti-matter measurements up to 10 TeV*

Indirect measurements (ground or space based)

- Science Cases: galactic-extragalactic CR transition, CR astronomy, new physics at HE
- Observables: - all particle energy spectrum, composition (muon content), anisotropies
- Pros: large acceptance, Cons: higher systematics

→ *next challenge: ..... (LHAASO, AUGER-PRIME)*

→ *next to next challenge: increase statistics at UHE (ground versus space)*

Cross section measurements at accelerators

- Secondary production in the interstellar medium (LHCB-SMOG,COMPASS?)
- Shower development in atmosphere (LHCF, ...SAS?)

GAMMA RAYS

Allow to identify sources and are sensitive to

- Cosmic rays (physics in high-density regions, e.g. near BHs)
- Nuclear phenomena (in keV or MeV regions)
- Decay/annihilations of new particles (WIMPs for example)
- Cosmology and properties of quantum vacuum, including axion density

Experimental scenario in medium and long (20 yr) term:

- **keV region:** ATHENA or similar X-ray experiments. CALET/GBM for nuclear astrophysics & DM search
- **MeV region:** crucial for nuclear astrophysics needs satellites as COMPTEL (1990). New missions (e-ASTROGAM, COMPAIR) 100 times more sensitive could profit of INFN know-how in Si trackers (2025+)
- **GeV region:** Fermi cannot be reasonably improved with present technologies: try to keep it in space till 2028. New space missions in discussion (HERD?)
- **sub-TeV and TeV regions**: CTA (2021-2050?) has no rivals in this essential region for fundamental physics and astrophysics. HAWC and LHAASO can contribute with their large FoV to the high-end (several TeV) region.
- **PeV region**: Only few sources could be visible in the North and less than a dozen in the South, all galactic. Experiments as HAWC+ (<- HAWC), LHAASO, TAIGA/HiSCORE provide a serendipitous coverage of the Northern sky. A large FoV experiment in the South, possibly starting at ~100 GeV, is highly desirable (LATTES?)

FRONTIERS OF NEUTRINO ASTROPHYSICS

Measurement of the CNO solar cycle

Relevant for the issue of solar metallicity, other stars --- INFN is in the forefront

Neutrinos from a galactic supernova as seen in scintillators

Neutral current events: Energetic, neutrino propagation --- competitive with Super-K

Borexino, then JUNO

Cosmic neutrinos discovered

IceCube has opened a new observational window: now we need to do better

- E>100 TeV quasi isotropic dominant component, presumably extragalactic
- E<100 TeV galactic contribution? can be probed only marginally with current means

Expected progresses with telescopes in the Northern Hemisphere

ANTARES

- Running and obtaining information on galactic contribution
- Participates in joint search data analyses with IceCube

KM3NeT

- A staged physics programme, *ANTARES X 10* under construction (off-shore Capo Passero)
- *WHAT NEXT? one cubic kilometer telescope*
- Much better angular resolution than IceCube => lower background, source identification
- Will monitor the Milky Way, including gamma ray sources and Galactic Center
- But also determination of mass hierarchy measuring atmospheric neutrinos (off-shore Toulon)