Snowmass2021 - Letter of Interest

Cosmic Ray Ensembles as a potentially new probe of Fundamental Physics

Topical Groups:

☑ (CF7) Cosmic Probes of Fundamental Physics
☑ (CF1) Dark Matter: Particle Like

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Abstract:
Cosmic Ray Ensembles (CRE) are very large, yet not observed particle cascades initiated above the Earth atmosphere. Such cascades could be formed both within classical models (e.g. products of photon-photon interactions) and exotic scenarios (e.g. result of decay of Super Heavy Dark Matter particles and subsequent interactions). Some of CRE might have a significant spatial extent which could serve as a unique signature detectable with the existing cosmic ray infrastructure taken as a network of detectors. This signature would be composed of a number of air showers with parallel axes. An obvious, although yet not probed, CRE „detection horizon" can be located somewhere between an air shower induced by an CRE composed of tightly collimated particles (preshower effect), and undetectable CRE composed of particles spread so widely that only one of them have a chance to reach Earth. Probing the CRE horizon with a global approach to the cosmic ray data, as proposed by the newly formed Cosmic Ray Extremely Distributed Observatory, defines an extensive scientific program oriented on the search for physics manifestations at largest energies known, with potential impact on ultra-high energy astrophysics, the physics of fundamental particle interactions and cosmology.

Introduction Within this project we aim at searching for the yet not checked multi cosmic-ray signatures that are composed of many air showers and individual particles arriving simultaneously to the human technosphere, mostly the Earth, so-called cosmic-ray ensembles (CRE). The signatures of CRE might be spread over very large surfaces which might make them hardly detectable by the existing detector systems operating individually. On the other hand, if these detector systems operate under a planetary (and beyond) network, as proposed by The Cosmic-Ray Extremely Distributed Observatory (CREDO) [1–3], the chances for detection of CRE will naturally increase. The components of CRE might have energies that practically span the whole cosmic-ray energy spectrum. Thus, all the cosmic ray detectors working in this range, beginning from smartphones (e.g. DECO [4], CRAYFIS [5], CREDO Detector[1], Cosmic Ray App[2] and pocket size open-hardware scintillator detectors (e.g. Cosmic Watch [6,7] or CosmicPi[3]) and low cost air shower detectors [8], through numerous larger educational detectors and arrays (e.g. HiSPARC [9,10], QuarkNet [11], Showers of Knowledge [12], CZELTA [13] to the professional infrastructure that receive or will receive cosmic rays as a signal or as a background (Pierre Auger Observatory [14], Telescope Array [15], JEM-EUSO [16,17], HAWC [18], MAGIC [19], H.E.S.S. [20], VERITAS [21,22], IceCube [23], Baikal-GVD [24], ANTARES Telescope [25], European Southern Observatory [26], other astronomical observatories, underground observatories, accelerator experiments in the the off-beam mode) could contribute to a common effort towards a hunt for CRE.

The scientific novelty of the CRE-oriented research is schematically illustrated in Fig. 1. The novelty is based on a general approach to large scale correlations of cosmic rays, with the ambition to consider the widest possible range of scenarios that can be verified on Earth through an observation of an ensemble of at least two particles or photons with a globally spread and coordinated network of detectors. In addition to testing spatial correlations of particles arriving simultaneously at the Earth, the general CRE strategy includes also searches for groups of spatially correlated cosmic-ray photons that might arrive at the Earth at significantly different times, with temporal dispersion of the order of minutes or more. Such phenomena have been reported in the literature [27,28], but they have not been observed

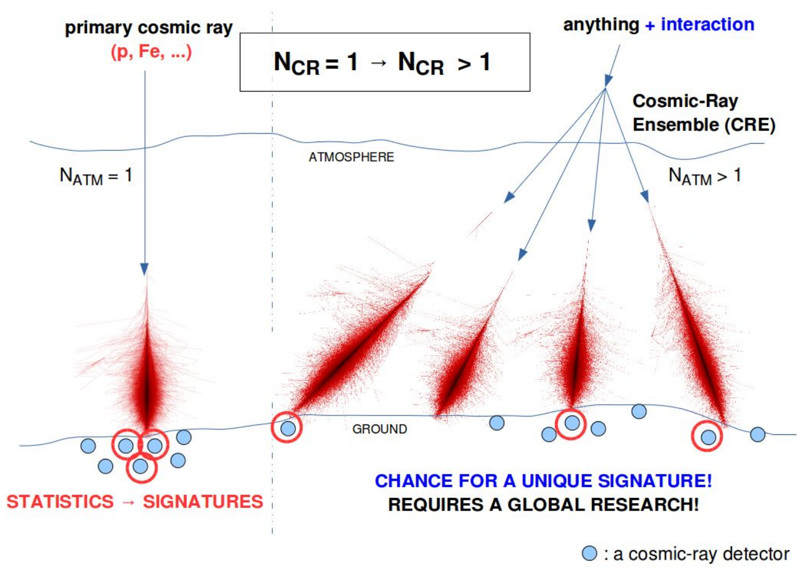

Figure 1: Cosmic-Ray Ensembles: a novelty in cosmic-ray research and in multi-messenger astroparticle physics.

[1] "CREDO Detector Mobile App - Information and Download ...." https://credo.science/credo-detector-mobile-app/. Accessed 4 Nov. 2019.
[2] "Cosmic Ray App." https://cosmicrayapp.com/. Accessed 4 Nov. 2019.
[3] "Cosmic Pi | The cosmic ray detector on your desktop." http://cosmicpi.org/. Accessed 4 Nov. 2019.

repeatedly until now. One of the CREDO capabilities is either to confirm or exclude a physical character of these outlying observations. One of the objectives of this project will be to develop an analysis framework that would enable relevant studies. If the existence of temporally extended groups of photons reaching Earth is confirmed, this might be an indication of sensitivity to spacetime structure. The analysis in this direction will resemble the studies on spacetime graininess performed by gamma astronomers [29], where X-ray and gamma ray cosmic data (energies up to TeV) were studied to conclude that space-time is smooth down to distances 1000 times smaller than the nucleus of a hydrogen atom (smaller than 10^{-18} m)[4]. However, the CRE approach potentially offers much more compared to the studies based on gamma ray data: the highest cosmic ray energies known exceed 10^{20} eV, and if such particles come to us within a CRE composed also of lower energy particle companions, then the sensitivity to the spacetime graininess might be correspondingly larger, i.e. even by 8 orders of magnitude. The key advantage of the proposed approach is that an 8 orders of magnitude progress in foundations of science can be reached using existing observatories and the infrastructure which is waiting in stores.

Feasibility The ongoing research concerning the **CRE studies** includes e.g. the first CRE modeling and detector response studies concerning interactions of ultra-high energy photons with the magnetic field of the Sun and of the Earth [30,31], two PhD projects concerning compact CRE (the preshower effect) [32], and formation and propagation of CRE in the Galaxy [33] which are planned to be completed this year, two engineering PhD projects concerning classification of particle track candidates in particle cameras [34], wireless communication in small arrays of cosmic ray detectors [35], and a few ongoing, yet not published scientific analyses concerning e.g. a detection of air showers with affordable detectors and checking the compatibility of the distribution of lengths of straight tracks in the CREDO smartphone data with the zenith angle distribution of muons[5]. The status of research related to Cosmic Ray Ensambles, dynamics of the scientific advances, and the increasing number of institutional members of the CREDO Collaboration (to date 39 institutions from 17 countries on 5 continents - 70% increase within the last 12 months; see the updated list) addresses quite adequately the feasibility issues concerning the interest being expressed with this letter. If it comes strictly to the quantification of the chances of observing CRE on Earth, in particular the preliminary work presented in Ref. [33] shows that within a scenario concerning the propagation of high energy electrons **within the Galaxy the horizon for a CRE observation is further than 10 kpc**, assuming a synchrotron emission of a primary electron at the Galaxy center, and taking into account both deflections in realistic galactic magnetic fields and the state-of-the-art assumptions concerning the opening angle at the vertex of the synchrotron emission. Moreover, the study presented in Ref. [30] concerning an interaction of ultra-high energy photons with the solar magnetic field indicates that **in case of extragalactic sources the CRE horizon might reach ~ 1 Gpc!** The latter outcome is obtained when taking into account the minimum distances between secondary TeV photons at the Earth: ~10^{-7}m, and shifting the source away, to astrophysical distances.

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[4] "Chandra Press Room :: NASA Telescopes Set Limits on ...." 28 May. 2015, https://chandra.harvard.edu/press/15_releases/press_052815.html. Accessed 31 Oct. 2019.

[5] The updated list of the CREDO publications can be found here: https://credo.science/publications.

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