The UHECR Snowmass White Paper
Mini-workshop #3

Coordinators – F. Sarazin, F. Schroeder, T. Venters

Lead conveners – A. Coleman, J. Eser, E. Mayotte, D. Soldin

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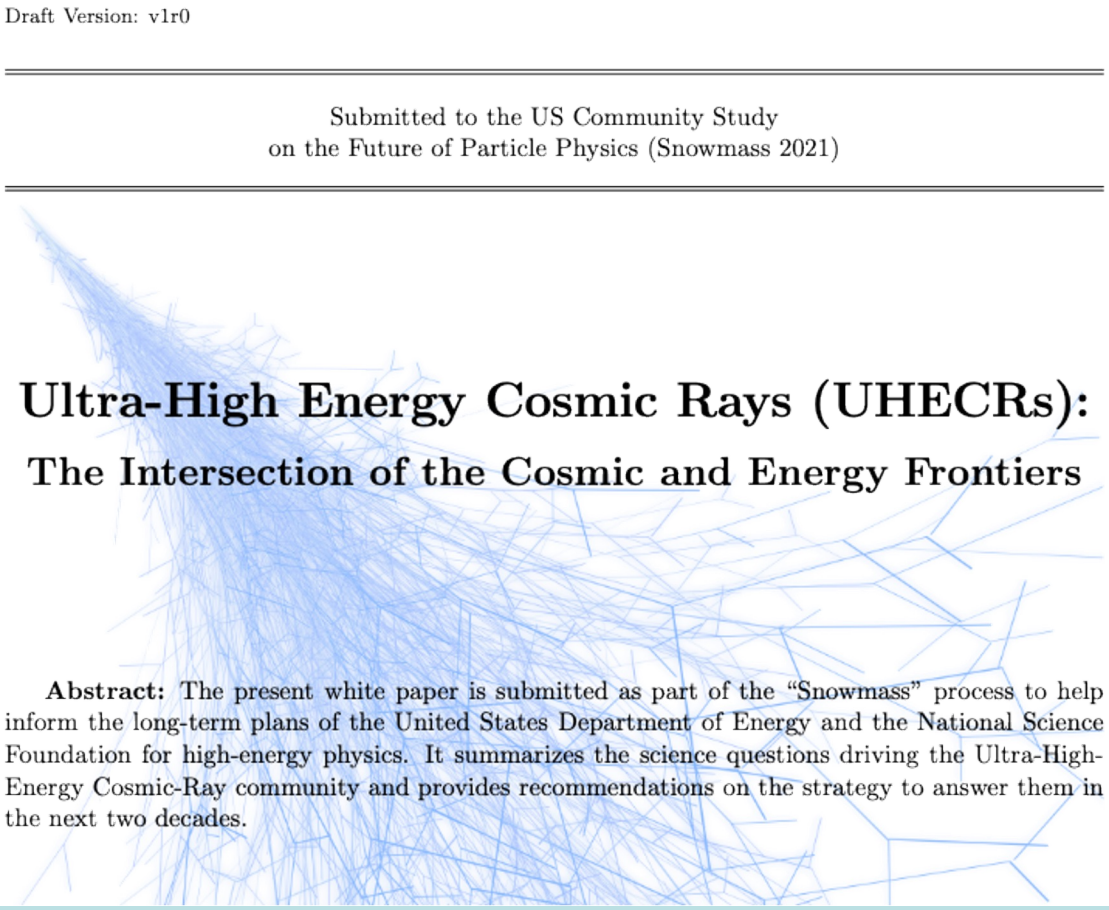

Draft Version: v1r0

Submitted to the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Ultra-High Energy Cosmic Rays (UHECRs):

The Intersection of the Cosmic and Energy Frontiers

Abstract: The present white paper is submitted as part of the "Snowmass" process to help inform the long-term plans of the United States Department of Energy and the National Science Foundation for high-energy physics. It summarizes the science questions driving the Ultra-High-Energy Cosmic-Ray community and provides recommendations on the strategy to answer them in the next two decades.

- 257 pages total, >98% complete
- A private copy was provided to CF7 conveners on March 15
- The WP was made available to the community for review on March 24
  - PDF
  - Comment sheet
- Upcoming ArXiv submission*:
  - Comment deadline to be included in v1r1 – Match 31st 5pm MT
  - Comment deadline to be included in v2r0 – April 8th 5pm MT

** See dedicated slide later in this presentation*

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- 97 co-authors
- Please let us know if someone is missing!
- Endorsement (not co-authorship) procedure in preparation

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- Even in the most optimistic scenario, the first next-generation experiment will be operational around 2030. AugerPrime and TA×4 should continue operation until at least 2032.
- IceCube and IceCube-Gen2 provide a unique laboratory to study particle physics in air showers. For this purpose, the deep detector in the ice should be complemented by a hybrid surface array for sufficiently accurate measurements of the air showers.

Experiment	Feature	Cosmic Ray Science*	Timeline
Pierre Auger Observatory	Hybrid array: fluorescence, surface e/μ + radio, 3000 km^2	Hadronic interactions, search for BSM, UHECR source populations, $\sigma_{\text{p-Air}}$	AugerPrime upgrade
Telescope Array (TA)	Hybrid array: fluorescence, surface scintillators, up to 3000 km^2	UHECR source populations proton-air cross section ($\sigma_{\text{p-Air}}$)	TAx4 upgrade
IceCube / IceCube-Gen2	Hybrid array: surface + deep, up to 8 km^2	Hadronic interactions, prompt decays, Galactic to extragalactic transition	Upgrade + surface enhancement; IceCube-Gen2 deployment; IceCube-Gen2 operation
GRAND	Radio array for inclined events, up to 200,000 km^2	UHECR sources via huge exposure, search for ZeV particles, $\sigma_{\text{p-Air}}$	GRANDProto 300; GRAND 10k; GRAND 200k multiple sites, step by step
POEMMA	Space fluorescence and Cherenkov detector	UHECR sources via huge exposure, search for ZeV particles, $\sigma_{\text{p-Air}}$	EUSO program; POEMMA
GCOS	Hybrid array with $X_{\max}$ + e/μ over 40,000 km^2	UHECR sources via event-by-event rigidity, forward particle physics, search for BSM, $\sigma_{\text{p-Air}}$	GCOS R&D + first site; GCOS further sites

2025 2030 2035 2040

*All experiments contribute to multi-messenger astrophysics also by searches for UHE neutrinos and photons; several experiments (IceCube, GRAND, POEMMA) have astrophysical neutrinos as primary science case.

Figure 2: UHECR upgraded and next-generation instruments with their defining features, main scientific goals, and timeline.

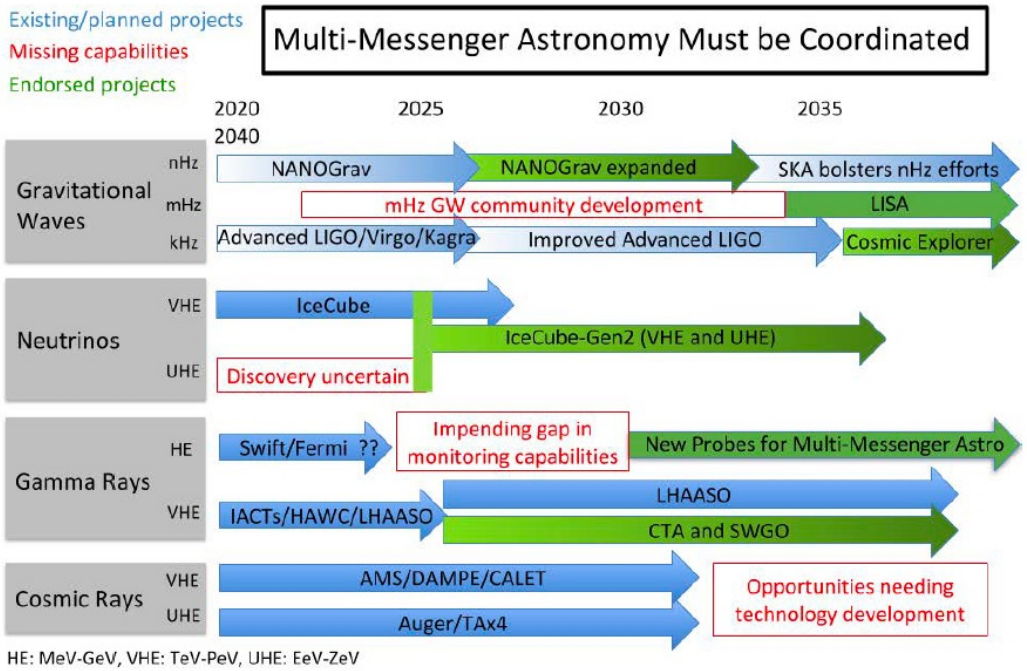

FIGURE L.4 Schematic high-level view of capabilities in different messengers over decades (blue: existing or planned, red: missing capabilities, green: endorsed new projects, dated by construction starts). Gradient shading indicates projects that can start taking data as construction proceeds. Not shown are many promising potential projects for which technology development is needed. With each messenger, the discovery prospects are outstanding; with multi-messenger observations, they could be transformative.

- A robust effort in R&D should continue in detector developments and cross-calibrations for all air-shower components, and also in computing techniques. This effort should include, whenever possible, optimized triggers for photons, neutrinos and transient events.
- To achieve the high precision UHECR particle physics studies needed to provide strong constraints for leveraging by accelerator experiments at extreme energies, even finer grained calibration methods, of the absolute energy-scale for example, should be rigorously pursued.

- The next-generation experiments (GCOS, GRAND, and POEMMA) will provide complementary information needed to meet the goals of the UHECR community in the next two decades. They should proceed through their respective next stages of planning and prototyping.
- At least one next-generation experiment needs to be able to make high-precision measurements to explore new particle physics and measure particle rigidity on an event-by-event basis. Of the planned next-generation experiments, GCOS is the best positioned to meet this recommendation.
- As a complementary effort, experiments with sufficient exposure ($\gtrsim 5 \times 10^5\,\mathrm{km}^2\,\mathrm{sr}\,\mathrm{yr}$) are needed to search for Lorentz-invariance violation (LIV) and other BSM physics at the Cosmic and Energy Frontiers, and to identify UHECR sources at the highest energies.
- Full-sky coverage with low cross-hemisphere systematic uncertainties is critical for astrophysical studies. To this end, next generation experiments should be space-based or multi-site. Common sites between experiments are encouraged.

- Based on the productive results from inter-collaboration and inter-disciplinary work, we recommend the continued progress/formation of joint analyses between experiments and with other intersecting fields of research (*e.g.* magnetic fields).
- The UHECR community should continue its efforts to advance diversity, equity, inclusion, and accessibility. It also needs to take steps to reduce its environmental impacts and improve open access to its data to reduce the scientific gap between countries.

Submission of the UHECR white paper to arXiv?

Dear co-authors,

the regular Snowmass process calls for White Papers (WPs) to be submitted to the arXiv for future reference (in topical Frontier reports for example).

Following the invasion of Ukraine by the Russian military, there have been calls not to prepare new scientific papers with scientists at Russian institutions. As it stands, this WP has three co-authors falling into this category. However, this WP was started early September and their contributions were received prior to the invasion. Hence, we would prefer to follow the good scientific practice of including all co-authors in the submission.

After some discussion with the Snowmass steering committee, it appears that the best course of action is to seek approval from ALL the co-authors to authorize the WP to be submitted to the arXiv. This needs to be an UNANIMOUS decision. We therefore ask you to authorize the submission of the WP to the arXiv, unless the rules of your country or institution forbid you to do so in this specific case.

Please fill the form below.

Thank you,

The coordinators and lead conveners of the UHECR WP

Google form to be distributed to co-authors

Name: *

Your answer

Email: *

Your answer

Do you authorize the coordinators to submit the UHECR white paper to the arXiv with co-authors listed with Russian institutions? *

- ◯ Yes
- ◯ No

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APS Condemns the Russian Invasion of Ukraine
February 26, 2022

The American Physical Society (APS) condemns the Russian invasion of Ukraine and is gravely concerned about its impact. APS stands in solidarity with the Ukrainian physics community and all people whose safety has been jeopardized, and whose homes, families and careers have been disrupted by the violence. As APS seeks ways to serve its members in Ukraine and Russia during this difficult time, it underscores its commitment to the principles expressed in the APS Statement on the International Nature of Science and International Scientific Cooperation and declares its support for the rights and freedoms conveyed in the Universal Declaration of Human Rights for all people. APS calls for a halt to hostilities and a peaceful end to the crisis.