Cosmic Ray Extremely Distributed Observatory: status and perspectives

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Outline:
- Introduction: Cosmic rays, preshower effect
- How to select muon like events from smartphones images
- Example of time clustering analysis
- Citizen science
- Summary
**Cosmic - Rays**

**Cosmic-rays**: energetic nuclei propagating in space at speeds close to light velocity. Discovered by Victor Hess in early 20th century.

- Power-law flux over many order of magnitude
- Two features: knee and ankle
- End of spectrum?
- Direct measured only below $10^{14}$ eV
- Measurement of air showers at higher energies

**Ultra High Energy Cosmic Rays (UHCRs), E > $10^{17}$ eV**
Cosmic-Ray mystery

Greisen-Zatsepin-Kuzmin (1966) – cosmic ray absorption in Cosmic Microwave Background CMB (1965):

\[ p + \gamma_{cmb} \rightarrow \Delta(1232) \rightarrow p + \pi^0 \quad \text{or} \quad n + \pi^+ \]

suppression of cosmic ray flux above energy of $4 \times 10^{19}$ eV (GZK-cut-off), maximum source distance of 50-100 Mpc

Still open questions:

> What’s their composition?

> Where do they come from?

→ anisotropies weakly correlated to known possible sources: active galactic nuclei, gamma-ray burst, …

> How do they reach such tremendous energies? (past the GZK cut-off!)

Do photons of very high energies (above $10^{15}$ eV) exist?
Extensive air shower

Extensive air shower – collision of primary particle in air produce a shower of relativistic secondary particles

Energy of primary particle $10^{18}$ eV

Muons are one of the EAS component

Atmospheric muons:

~ 1 particle/cm²/minute

energy of muons ~$4 \times 10^9$ eV (4 GeV) at sea level
Motivation: looking for Cosmic Ray Ensembles (CRE)

Typical strategy: looking for ONE shower i.e. Pierre Auger Observatory, Telescope Array, IceCube ....

New strategy: Looking for multiple air showers correlated in time

CREDO

3000 km²

762 km²

1 km³
Classes of CRE

\[ N_{\text{ATM}} \geq 1: \text{untouched ground} \]

\[ \gamma_{\text{UHE}} \]
(e.g. \(10^{20}\)eV)

\[ \Delta x: \approx \text{few km} \]

\[ \text{obvious detection} \]

\[ \Delta x < \text{Earth size} \]

\[ \text{obvious (unchecked) "between"} \]

\[ \Delta x > \text{Earth size} \]

\[ \text{obvious extinction} \]
Example of CRE: Preshower in vicinity of Sun

Typical particle distribution at the top of atmosphere

\[ \gamma_{UHE} \]
(e.g. \(10^{19}\) eV)

\[ B_{SUN} \]
\[ e^+e^- \]

SUN

ATMOSPHERE

EARTH

with PRESHOWER

Distribution of photons \((E > 10^{13} \text{ eV})\) at the top of the atmosphere.

\[ E_\gamma = 10 \text{ EeV}, \text{ Impact parameter} = 2.5R_S. \]

Example of CRE: Preshower in vicinity of Sun

Typical particle distribution at the top of atmosphere

Cosmic-ray Extreamly Distributed Observatory

http://credo.science/
Cosmic-ray Extremely Distributed Observatory

Citizens strengthen trigger capabilities of the educational arrays with smartphone networks

\[ \gamma_{UHE} \quad (e.g. 10^{20} \text{eV}) \]

Citizens browse the data looking for "improbable time-space coincidences"

1) \( t_n - t_1 < \sim 1 \, \mu s \)
2) \( t_1 < \ldots < t_n \)

→ indirect search for New Physics manifestations!
→ verification of "classic" QED predictions (preshower @ Sun)
Mobile application

Smartphone application developed by CREDO collaboration

http://credo.science
https://play.google.com/store/apps/details?id=science.credo.credomobiledetektor

CREDO detector

Code of application is public on GitHub

Level 2: data acquisition
Charged-coupled devices (CCD)

Smartphones have a detector of typical 4 x 4 mm²
→ can detect cosmic rays

→ large number required (10⁶)
(astro-ph 1410.2895, astro-ph 1505.04777)
Typical classes of events from smartphones

… from api.credo.science

How to extract signal-like events (muon like)?
Simple filter

**Discrimination parameters:**

- **SIZE:** sum of illuminance in all pixels above certain defined threshold
- **LENGTH/WIDTH:** the ratio of major to minor axis of ellipse

**Selection criterion:** \( \log_{10}(\text{SIZE}) < 1.7 \)

**Muon like events**

- **149 events**

**Artefakty**

**Log\(_{10}(\text{SIZE})\) = 0.74**

Length/Width = 5.25

**Log\(_{10}(\text{SIZE})\) = 1.05**

Length/Width = 3.0

**Log\(_{10}(\text{SIZE})\) = 1.18**

Length/Width = 2.0

**Log\(_{10}(\text{SIZE})\) = 1.07**

Length/Width = 8.2

**Log\(_{10}(\text{SIZE})\): length/overwidth**

- **Artefakty**
- **Muon like events**

**Team: IFJ**
Time-clustering

How to find significant cluster of events in time?
Finding point sources in the sky means to locate an excess of events from a particular direction over the background.

The signals events may present additional features: different energy spectrum or time structure.
Simple method: search for time cluster

Data distribution

Test Statistics (TS)

TS := doublet duration*

*for other multiplets different definitions assumed

RESULT:

P-value as the fraction of events below TS_data

\[ P\text{-value} = \frac{S_1}{S_1 + S_2} \]
Application of the method to the smartphone data

We consider not only doublets but other multiplets like 3, 4, ..., 15-plets

Results: Flare - cluster of 6 events:
- Start of possible flare: 10.02.2018 22h 49m 35s
- End of possible flare: 11.02.2018 00h 36m 16s

Significance: p-value=0.08, signific.=1.4 σ
Public engagement as a scientific tool

The match: “IFJ” vs. “Team Rzezawa”

Discipline: catching secondary cosmic ray particles with mobile devices with CREDO Detector

When? 16.11.2017, 11:00 – 12:00

Where? IFJ PAN, Gimanzjum Publiczne Rzezawa, Poland, world

Transmitted live: CREDO YouTube Channel

Number of registered players: 32:30
Number of caught particles: 12:4
Final score: -135 do -257

Level MAX: fun and emotions
... and online data analysis
CREDO Monitor

CREDO monitor is a daily automated list of tasks whose ultimate objective is a search of Cosmic Ray Ensembles (CRE).

- **Data Acquisition/Migration**: Acquisition of data and transfer to the central server.
- **Data Conversion**: Conversion of data from different detectors/sources into a common format.
- **Data Preprocessing**: Data sorted in time and merged into the final form (daily sets).
- **Analysis**: A preliminary scanning done to look for possible CRE signatures.
- **Map Production**: Creation of maps for cosmic ray arrival time as a function of geographic locations.
- **Map Sharing**: Sharing the map for analysis/further classification.


The storage, monitoring and computing tasks of CREDO are hosted by ACC Cyfronet AGH-UST.
The Zooniverse enables everyone to take part in real cutting edge research in many fields across the sciences, humanities, and more. The Zooniverse creates opportunities for you to unlock answers and contribute to real discovery.
and social media
Level 1:
growth/scale generation
MEDIA ABOUT US

EurekAlert! The Global Source for Science News

PUBLIC RELEASE: 12-JUN-2018
CREDO: You too can help unveil the deepest puzzles of the universe
THE HENRYK NIEWODNICZANSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

Cracow, 12 June 2018
Are astrophysical phenomena occurring millions or even billions of light years from Earth responsible for some diseases? Does dark matter really exist? What is the true nature of our spacetime - is it continuous or digital? Can the exotic effects of quantum gravity be tested experimentally? Install the CREDO Detector app, become part of the largest particle detector in history and help

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CREDO @ Science Picnic, Warsaw, 9/06/18
7 zdjęć

CREDO @ Science and Art Festival in Kraków, May 2018
10 zdjęć
Cosmic-Ray Extremely Distributed Observatory (CREDO)

Enables a strategy for a global analysis of cosmic-ray data to reach the sensitivity to extremely extended cosmic-ray phenomena, we call them super-preshower, invisible for individual detectors or observatories. So far, the cosmic-ray research has been oriented on detecting single air showers only, while the search for ensembles of cosmic-ray events induced by super-preshower is a scientific terra incognita.
CREDO: a unifying, global cosmic-ray project: GeV – ZeV
→ completing the closest accessible approach to GUT scale

All kinds of detectors can contribute: CR observatories, smartphones, muon detectors, etc...
→ collaborations already ongoing with HiSPARC, Bajkal-GVD, CYFRONET (data storage), etc...

Strong humanistic motivations: ASTRO / GEO (earthquake prediction) / BIO (health hazards) / Citizen Science

We invite the entire physics community to contribute to CREDO efforts!
CREDO Monitor

Real data analysis