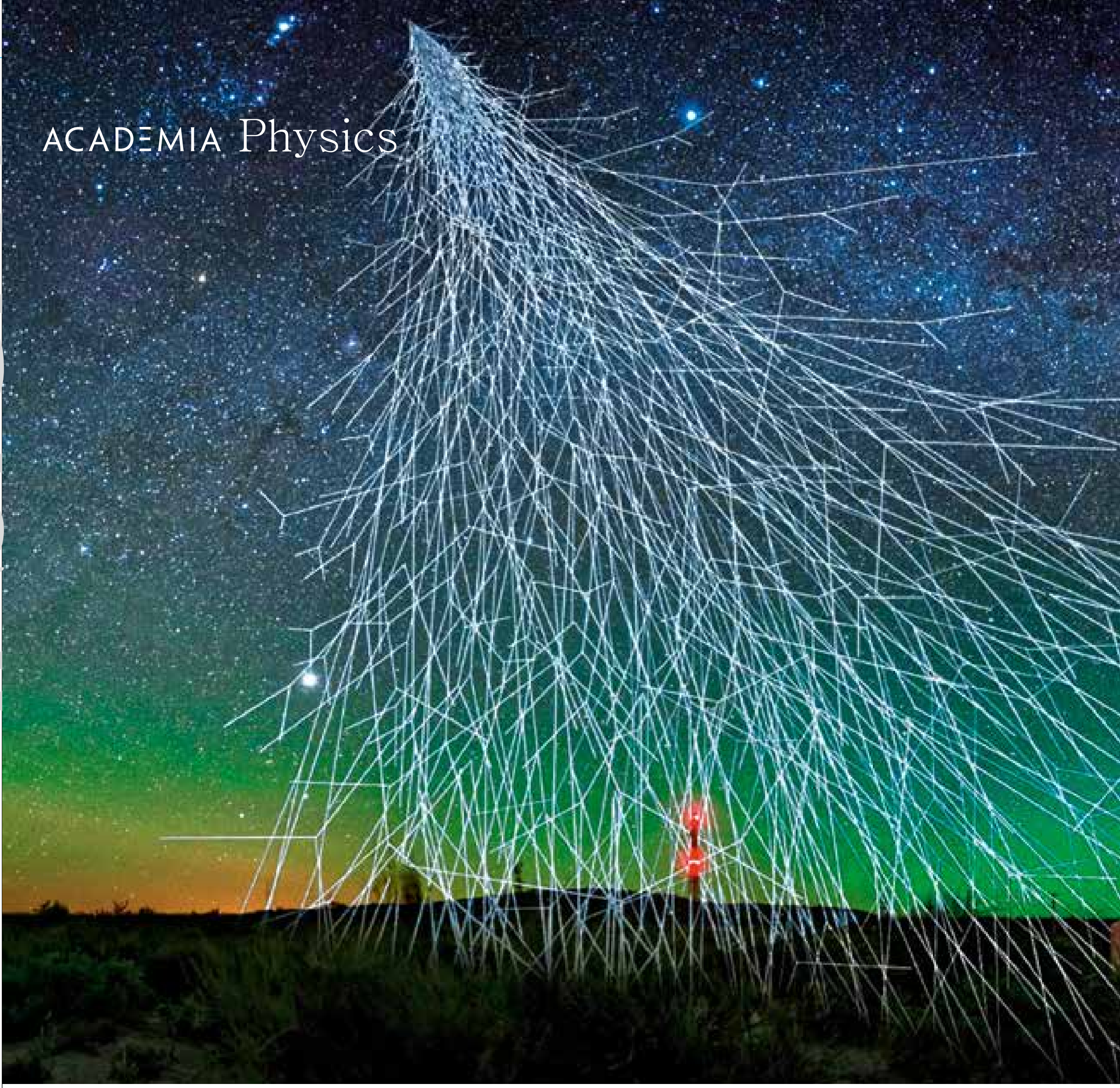

Tales of a Particle Hunter

We talk to **Prof. Piotr Homola** from the Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences in Kraków, about his search for cosmic ray ensembles.

CREDO

Piotr Homola, PhD, DSc
is an astrophysicist and Associate Professor at the PAS Institute of Nuclear Physics. He works at the Department of Cosmic-Ray Research where he studies cosmic ray ensembles and ultra-high-energy cosmic rays and contributes to the construction and development of the Cosmic-Ray Extremely Distributed Observatory (CREDO).

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ACADEMIA: **Cosmic radiation – what is it and what's so mysterious about it?**

PIOTR HOMOLA: If we are serious about improving our understanding of the Universe, we should be interested in recording and elucidating all types of signals coming from it. One such channel of information is cosmic radiation. The particles that comprise it vary in terms of their energy by as much as ten orders of magnitude; this means that those with the lowest energy levels have 10^{10} less energy than those with the highest levels. The flux of these particles, calculated as the number detected per unit of surface area of the detector and per unit of time, decreases rapidly with energy. This means that particles with the highest energies are very rarely detected on Earth. As such, statistical data describing particles with the highest energies is scarce, which is perhaps why those particles seem the most exciting. For particles with energies on the order of 10^{20} electronvolts, we can expect to observe no more than about one per km^2 per millennium! To make such a momentous observation, we need targets with extremely large surface areas. Existing detectors cover thousands of square meters, but this is still insufficient to register statistically significant numbers of particles with energies exceeding 10^{20} electronvolts. These low figures mean we still don't fully understand what kinds of particles they are and how they manage to reach Earth. But solving this puzzle could entail a breakthrough in our understanding of the Universe and objects within it.

What kinds of objects?

Our nearest source of cosmic radiation is the Sun. It emits particles with energies on the order of 10^9 electronvolts. Other objects, such as stars, supernovas, quasars and active galaxy nuclei, also emit particles with similar or higher energies; some of them reach Earth, we call them cosmic rays. Certain cosmic rays may also have been created as a result of the decay of hypothetical, massive particles formed at the early stages of our Universe. If the study on cosmic rays resulted in our being able to confirm the existence of these particles, it would mark an important step towards solving the puzzle of Dark Matter.

How are cosmic rays observed?

Since the cosmic-ray flux decreases rapidly with increasing energy, we can indirectly observe only particles with low energies, up to 10^{15} electronvolts. The Earth's atmosphere shields us from cosmic rays, so more accurate observations are made by instruments mounted on satellites or stratospheric balloons. In this case, the flux of particles which gets close to our planet is sufficiently large to be detected directly.

However, higher energy cosmic rays can only be detected indirectly by observing a phenomenon known as an extensive air shower. High energy particles do not reach the Earth's surface, but they interact with air molecules to create a cascade of secondary particles. These cascades are more likely to be observed than individual primary particles because they are much larger. For primary particles with energies of the order of 10^{19}–10^{20} electronvolts, the diameter of the front of the shower can exceed ten kilometers; this is the area over which the secondary particles which reach Earth are dispersed. This makes such a shower a physical object which can be observed using a range of techniques.

> Anyone can take part in the CREDO experiment. Even a ten-year-old, as long as he or she has an enthusiastic attitude towards science. And a smartphone.

The most common and effective terrestrial detection technique uses an array of particle counters spaced at different distances from one another. For example, the Pierre Auger Observatory in Argentina, the largest detector of cosmic radiation on Earth, has a network of approx. 1600 detectors spaced 1.5 kilometers apart. They cover an area of about 3000 square kilometers, allowing them to capture even very rare particles. Another technique works on registering fluorescence light, generated as a result of interactions between particles from an air shower with molecules in the atmosphere. Air molecules get excited by particles of an air shower and then de-excite by emitting radiation which can be observed using special telescopes. Indirect studies of cosmic radiation are difficult, since we can only observe secondary particles; and it is only the properties of the cascades of secondary particles which let us speculate on the properties of the original particles. The direction of their arrival is the easiest to reconstruct. We are also able to estimate their energies with a relatively good accuracy, but determining the type of particles we are detecting – protons, heavier atomic nuclei or photons – is the most difficult. The trouble is that the air showers initiated by these different types of high-energy particles are very similar. Only when we have more data can we speculate on the composition of the flux of cosmic radiation. However, determining the type of individual high-energy particles arriving from space is currently beyond the capacity of the equipment and methods available today.

Tell us about the CREDO project.
CREDO stands for Cosmic-Ray Extremely Distributed Observatory. It's visualized in the project's logo by the letter "O" as a map of the globe with colored dots showing the locations of detectors. Distributing the equipment over as large an area as possible makes it more likely to detect the phenomenon we are looking for: a Cosmic Ray Ensemble (CRE). The front of a single large air shower can have a diameter exceeding ten kilometers. When the phenomenon stretches over thousands of kilometers, it is most likely not an individual shower but a cluster of showers. These are the events we are trying to track; we focus on detecting temporal coincidences between showers, or even individual secondary particles registered by detectors which could be thousands of kilometers apart.

Two things are key in this strategy. First, the higher the number of detectors and the greater the area they are distributed over, the better. That's why CREDO aims to analyze practically all data from all experiments – as long as the observatories are willing to share it. Of course we need to work with professional stations, such as the Pierre Auger detectors, but it is also very important to include as many amateur detectors as possible. The simplest of those are smartphones with cameras, i.e. photodetectors. When users download the CREDO app, their phone become research tools. Trying to capture cosmic radiation using ordinary devices forms an important part of CREDO's strategy. Of course we must remember that if we really are able to collect the data from all or most of the existing experiments, we would be dealing with vast amounts of data whose analysis would require immense computing power, both in terms of storage and processing. This brings me to the second point, which is that we will need a huge team of people to look at and analyze all this data.

How large is the team we talking about?
We would probably need more people than the population of qualified scientists, which is why we have been developing research methods accessible to laypeople from the project's onset. We need their help with acquiring data using their smartphones, and with preliminary processing of this data. We are preparing detailed instructions and training courses on the subject.

I have a smartphone – does that mean I could take part in your program?
Anyone can take part! If a ten-year-old has a smartphone and enthusiasm for science, that's great. All you

need to do is go to the credo.science page and find the section titled CREDO Detector, which will tell you where to download the app, how to use it and how to share your experiences with other users. Or just can simply search for the CREDO Detector in Google Play.

And then I'll be contributing to a project spread around the globe?

The app was launched during the CREDO Symposium on 30 August 2017, and it was an immediate hit. Interest grew when we made it available on Google Play, but we still have some way to go. CREDO's strategy is rooted in disseminating the project among users, so we need to popularize it and the app around the globe if we are to reach our research goals. Our activities towards promoting CREDO must be held on a global scale, which is why we need to be talked about by traditional and social media and at academic conferences. We need to engage as many people as possible, especially potential partners and colleagues who are passionate about science, and young people are key in this. The app needs to have a good playability factor, not unlike that of Pokemon – except this time users get to "catch" fascinating, real objects which have arrived from far away in space.

Why is it essential for the smartphone to have a camera?

Cameras have light sensors which can be used to detect particles other than photons. Our app requires the camera to be shielded from visible light. In practical terms, it means you need to place the phone in a box or cover the camera with dark tape. Particles of secondary cosmic radiation can be registered any time – for example when you're out walking your dog – as long as you remember to cover the camera lens. And it can be worth taking a power-bank, because leaving the app running can run down the battery rather quickly. I should also add that the best results are obtained when the phone is in a horizontal position to make the most of the camera's surface area, because we expect the particles to arrive from above, more or less vertically. Given all this, the best time for running the app is actually at night. Can you think of an easier way of contributing to cutting-edge scientific research than while sleeping? Just cover the camera lens, plug in your phone, make sure your internet connection is on and you're away. Particles will turn up by themselves, perhaps bringing major scientific breakthroughs.

You can follow this with another stage: if your phone detects particles, you can also analyze them, perhaps to show that these particles in fact form part of a greater whole – a massive ensemble of cosmic rays, distributed over time and space. Detecting such a phenomenon would constitute a major discovery, potentially leading to a long-awaited breakthrough taking physics beyond the Standard Model, most likely both in cosmology and in particle physics. Wouldn't it be great if it turned out that a discovery of a kind that the scientific circles have been awaiting with bated breath was made possible, to some extent, thanks to you? Personally, by detecting mysterious particles with your own phone? We hope that this sense of personal contribution will motivate many people to join our project.

The idea of encouraging people to join major research projects alongside experts in this way is known as citizen science. And this participation of the public should also be reflected in citations, in that all individuals who contributed to a particular result have a right to be listed as co-authors. We feel strongly that citizen science will be key for CREDO's success. We hope – expect, even – the list of our co-authors to potentially run into the millions, which of course will pose a brand new problem for publishers.

It also poses a major challenge for you as scientists, since once these millions of users collect the data and run preliminary analysis, you will then need to bring it together and interpret it.

Yes, of course. The work will need to be automated as much as possible, but we will still need huge teams of analysts. To turn CREDO's aims into reality, the project requires far-reaching international collaboration. In terms of actually gathering and processing data, we are partnered with the Academic Computer Centre Cyfronet at the University of Science and Technology (AGH) in Kraków. We are delighted to be working with world class experts on computing and digital security.

Does your project supplement traditional methods of detecting cosmic rays?

Yes, it does. Ongoing studies allow researchers to detect and study individual particles, disregarding possible correlations in time. CREDO aims higher: if we detect even just two particles which we can confidently describe as having journeyed through the Universe together, it will constitute a major breakthrough. We believe that cosmic ray ensembles are formed somewhere in the Universe, so if we were able to detect and describe them, it would give us plenty to think about. CREDO is a pioneer in this field, since no one has attempted such observations before. Of course we don't know if we will be successful; it could turn out that this terra incognita really is a desert, but it could also be a fascinating land filled with myriad objects. In any case, as long as we publish our findings we are driving science forward. If what we find is a desert, we have a publication about this desert – but if we do find a previously unseen phenomenon, we'll certainly be popping open the champagne!

INTERVIEW BY ANNA ZAWADZKA

CREDO THE QUEST FOR UNEXPECTED