On the possible method of identification of two probably cognate Extensive Air Showers

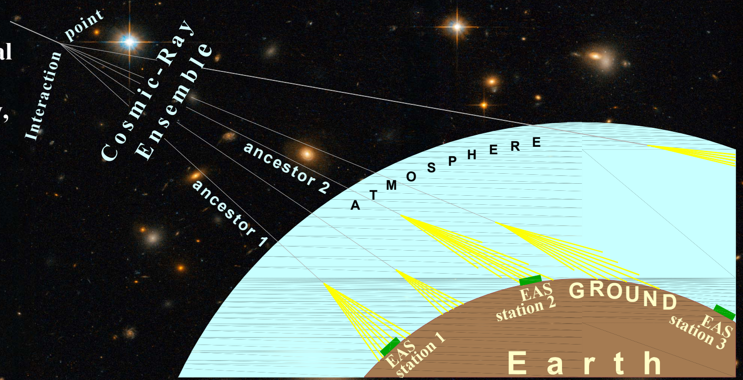
Yu. Verbetsky, M. Svanidze, D. Beznosko, P. Homola: on behalf of the CREDO Collaboration

ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany 37th International Cosmic Ray Conference 12–23 July 2021

CREDO THE QUEST FOR THE UNEXPECTED

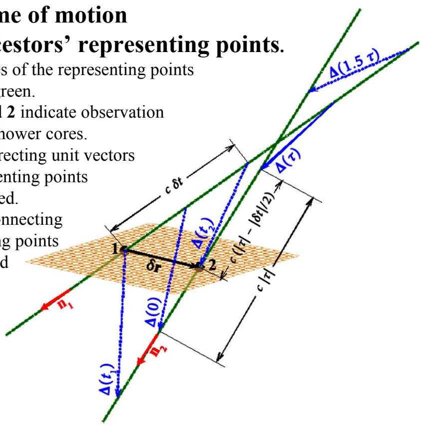
GELATICA PROJECT

A high-energy cosmic particle can interact with matter or radiation existing in the surrounding Space and generate a beam of particles called the Cosmic Ray Ensemble (CRE). These particles can reach the Earth's atmosphere and generate in it almost simultaneously several Extensive Air Showers (EAS or "showers") at a great distance from each other. The study of such EAS groups can advance in knowledge about the properties of interactions at high energies of their ancestor particles, about the properties of the Space environment and, possibly, about the properties of Dark Matter. For implementation of such studies, a method was proposed for selecting the couples of historically proximal EAS-s, whose ancestor particles were so spatially close in their past that it is permissible to assume their common origin.



The scheme of motion of two ancestors' representing points.

The trajectories of the representing points are shown in green.
Symbols **1** and **2** indicate observation points of the shower cores.
The motion directing unit vectors of both representing points are shown in red.
The vectors connecting the representing points at the specified moments are shown in blue.



Two Extensive Air Showers are detected by two remote EAS-observing stations and the cores' positions of both showers are located together with detection of the showers' occurrence times and their arrival directions.

Measured values		Some useful derived values	
Radius-vectors of two showers' cores observation points	$\mathbf{r}_{01},\ \mathbf{r}_{02};$	$\delta\mathbf{r} = \mathbf{r}_{02} - \mathbf{r}_{01}$	
with their covariance matrices	$\mathbf{M}_1,\ \mathbf{M}_2;$	$\mathbf{M} = \mathbf{M}_1 + \mathbf{M}_2$	
The times of those showers'	$\hat{t}_{01},\ \hat{t}_{02};$	$\delta t = \hat{t}_{02} - \hat{t}_{01}$	
observations with their variances	$\sigma_{t1}^2,\ \sigma_{t2}^2;$	$\sigma_{\delta t}^2 = \sigma_{t1}^2 + \sigma_{t2}^2$	
Unit vectors of the shower fronts' motion	$\mathbf{n}_1,\ \mathbf{n}_2;$	$\delta\mathbf{n} = \mathbf{n}_2 - \mathbf{n}_1;$	$\langle\mathbf{n}\rangle = (\mathbf{n}_1 + \mathbf{n}_2)/2$
with their covariance matrices	$\mathbf{D}_1,\ \mathbf{D}_2;$	$\mathbf{D} = \mathbf{D}_1 + \mathbf{D}_2;$	$\mathbf{D}/4$

Kinematics

The variable vector connecting at the moment t two ancestor particles' representing points moving uniformly in straight lines depends linearly on this running time:

$$\tilde{\mathbf{\Delta}}(t) = \mathbf{r}_2(t) - \mathbf{r}_1(t) = \left[\delta\mathbf{r} - \langle\mathbf{n}\rangle(c\,\delta t)\right] + \delta\mathbf{n}\cdot ct$$

As the time difference between two "relativistic events" is zeroth-order by definition, the squared interval

$$s^2(t) = -(c\cdot 0)^2 + \tilde{\mathbf{\Delta}}(t)^{\mathrm{T}}\cdot\tilde{\mathbf{\Delta}}(t)$$

is spacelike one. This interval has the smallest value at the moment:

$$\tau = -\frac{1}{c}\cdot\frac{(\delta\mathbf{r}^{\mathrm{T}}\delta\mathbf{n})}{(\delta\mathbf{n}^{\mathrm{T}}\delta\mathbf{n})}$$

The variable connecting vector at the moment of the points' closest approach obtains the value:

$$\mathbf{\Delta}_\bullet = \tilde{\mathbf{\Delta}}(\tau) = \delta\mathbf{r} - \langle\mathbf{n}\rangle(c\,\delta t) - \frac{(\delta\mathbf{r}^{\mathrm{T}}\delta\mathbf{n})}{(\delta\mathbf{n}^{\mathrm{T}}\delta\mathbf{n})}\cdot\delta\mathbf{n};$$

The Lorentz-invariant space-like interval $\Delta_\bullet = |\mathbf{\Delta}_\bullet|$ between the representing points at the moment of their closest approach as a measure of the *historical proximity* of the showers of the given pair.

The variations σ_τ^2, σ_Δ^2 of the values defined above can be calculated by obvious but lengthy way

Two showers' cognate verification Lorentz-invariant dimensionless parameters

If the ancestors of a pair of showers are suspected in common origin, they must possess the following properties:

- Both representing points have approached with each other *before* the observation of the earliest shower by one of the EAS stations, i.e. $\tau < \min(t_1,\ t_2) = -|\delta t/2| < 0$
- The estimation of minimal value of the interval $\Delta_\bullet$ between the representing points of both ancestors of the observed showers has nonsignificant difference with anticipated zero distance.

Two showers' *time **S**equencing* parameter

$$S = \operatorname{arsinh}\left(c\left(\tau + |\delta t|/2\right)/|\delta\mathbf{r}|\right)$$
$$-\infty < S < \infty$$

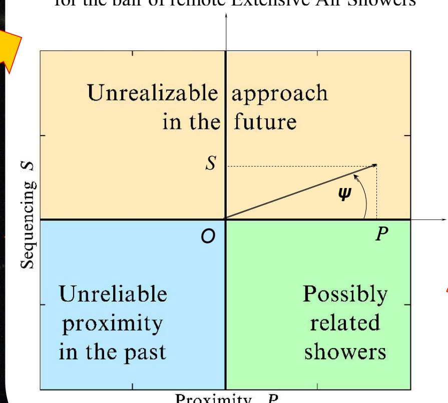
Two showers' *historical **P**roximity* parameter

$$P = -\ln\left(|\Delta_\bullet|/(k\cdot\sigma_\Delta)\right)$$
$$-\infty < P < \infty$$

The optional factor k adjusts the strictness of the *historical proximity* definition. The choice of optional coefficient k is the matter of compromise and agreement.

The plane of verifying parameters

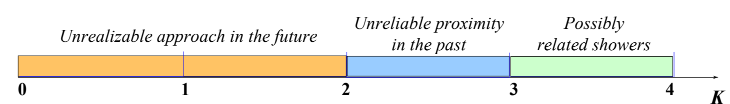
for the pair of remote Extensive Air Showers



Combined verifying criterion of possible historical proximity of both observed showers

$$K = \frac{2}{\pi}\Psi = \frac{2}{\pi}\operatorname{arctg}\left(\frac{S}{P}\right)$$

The criterion K defines the quadrant of (P, S) plane containing the point corresponding to kinematic properties of the pair of remote EAS-s.



Hubble Heritage: Coma cluster of galaxies