Can a human eye see an air shower in Cherenkov light ?

Razmik Mirzoyan

Max-Planck-Institute for Physics

Munich, Germany

Human eye as a light sensor for observing an air shower

- Let us dwell on a question: can we see air showers with bare eyes ? Let us start estimating
- The diameter of a human eye in the night is 6-7 mm, i.e. it covers an area of ~30 mm^2 = 0.3 cm^2 = 3 x 10^{-5} m^2
- Photon density of a 1 TeV γ shower on the ground (~ 2 km a.s.l.), within a disk of a radius of ~130m is ~130 ph/m^2 for the (λ ~ 300 – 600) nm
- Typically a human eye can see in the range (λ ~ 400 – 650) nm
- Assume we can see ~100 ph/m^2 from a γ = 1 TeV (the equivalent energy for the hadron to produce comparable light will be ~3 TeV; at this energies only ~1/3 of hadron energy goes into $\pi^0 \rightarrow 2\gamma$)

Human eye as a light sensor for observing an air shower

- From 1TeV γ (or from a ~3 TeV hadron shower) an eye will receive

  3×10^{-5} ph/m² x 100 ph = 3×10^{-3} ph
- Let us keep in mind that the Light of Night Sky (LoNS) has the intensity of 2×10^{12} ph/sr s m² for (λ ~ 300-600 nm)
- To see an image of an EAS one needs to “measure” ~100 “photo electron” (ph.e.) signal
- Assume an eye has been accommodated in dark for a few hours; then its photo detection efficiency could be as high as 15 – 20 % in green (you can try to guess why in green);
- Let us take 20% efficiency; the requested flux into an eye will be 100 ph.e. /0.2 = 500 photons

Human eye to see an air shower ?

- The requested photon flux on the ground will be

  500 photons / 3 x 10^{-5} m^2 = 1.67 x 10^7 photon/m^2
- Now we need to find out the energy of a γ shower, which can produce this amount of light on the ground
- Assume a linear relation exists between shower E and number of photons (this is largely true);
- If a γ of 1 TeV produces 100 photons/m^2, then we will need a γ shower of energy 1.67 x 10^5 times higher for producing 1.67 x 10^7 photon/m^2 on the ground, i.e. 1 TeV x 1.67 x 10^5 = 167 PeV

  (remember this is true for γ)

Human eye to see an air shower ?

- For a hadron to produce similar amount of light compared to the γ of 167 PeV, at these high energies one will need ~2 times higher E, i.e. 2 x 167 = 334 PeV
- Asume a shower image in the sky covers an angular area of 0.15°x 0.30°= 0.045 deg.^{2} → circle with ~0.12°radius (0.15°x 0.30° is the shower *width x length, i.e. the area of the ellipsoid*)
- The corresponding solid angle will be $2\pi \times (1 - \cos\theta) = 1.4 \times 10^{-5}$ sr;
- Note that human eye has a resolution of 1‘ = (1/60)°, so no problem to see the image of the above shown size
- Integration time of the human eye is ~ 30 ms

Reaction of the Human Eye to LoNS and how long should I look to see an EAS

- Integrated noise from LoNS will be ~ 2 x 10^{12} ph/sr s m^2 x 3 x x 10^{-5} m^2 x 3 x 10^{-2} s x 1.4 x 10^{-5} sr = 25 photons => (5 ±√5) ph.e. = (5 ± 2.2) ph.e.
- the signal/noise ratio will be 100ph.e./2.2 ph.e. = 45 (no problem with this, too good)
- We know that a single telescope operating above the γ threshold of ~1 TeV (or hadron threshold ~3TeV) will produce a shower trigger rate of ~ 1 Hz (mostly hadrons)
- The cosmic ray integral rate scales with energy as ~ $E^{-1.7}$
- The rate of 334 PeV hadron showers will be less than the rate of 3 TeV hadron showers by ~ 2.6 x 10^9 times

How long should I wait to see an air shower with my bare eyes ?

- → for observing one single event one will need on average to wait 3.8×10^8 s, i.e. 12 years (taking into account that dark nights are only part of the day, at least 5 times longer,

  i.e. ≥ 60 years)

A possible answer to the formulated question