# The mass question by the high energy cosmic ray detections

Imre Czovek @ http://www.geocities.com/iczovek

The following detector types are used to measure the above TeV cosmic ray:

- *Balloons* at 30 km high, equipped with scintillation or silicon detector, gas proportional detector, Cherenkov light detector, But it is not possible to measure the particle mass. Only the particle charge and energy loss is measured.
- *Ground array detectors* equipped with scintillation and Cherenkov light detector. The energy loss of primer particle is measured by secondary particles of air shower.

These measurements are validated with GEANT4 or other Monte Carlo simulations and with electron accelerator pencil beam.

I would like to show the primer particle mass is not known and thus the 10 TeV/amu cosmic ion energy is over estimated. I think the primer "particle" candidates could be ionized space dust, or not fully ionized ions eg.: $^{238}U^{++}$, molecules. The measured charge is not equal with the atomic number; from the measured energy $E=\gamma mc^2$ $\gamma$ and m is unknown.

The measured/calculated energy loss:

Bethe-Bloch energy loss formula

$$\left.\frac{dE}{dx}\right]_{T<T_{cut}} = 2\pi r_e^2 mc^2 n_{el} \frac{(z_p)^2}{\beta^2} \times \left[\ln\left(\frac{2mc^2\beta^2\gamma^2 T_{up}}{I^2}\right) - \beta^2\left(1+\frac{T_{up}}{T_{max}}\right) - \delta - \frac{2C_e}{Z}\right]$$

The Bethe Bloch formula contains the classical electron radius and mass.
This formula describe the secondary electron energies in the air shower,
or the primary energy loss in the balloon experiments. This formula is sensitive to the charge ($Z_p$), but isn't sensitive to the particle mass, and velocity $\beta = \frac{v}{c}$.

The velocity dependence is negligible on high energies.
The proton betas on 100 GeV and 10 TeV: 0,99995 and 0,999999995.
Their ratio $1 \pm 5 * 10^{-5}$ is negligible.

## Uncertain detecting methods

In **air shower detection** the measured ionization is the same in the following two cases:

100 ions * 100 GeV = 1 particle * 10 TeV.

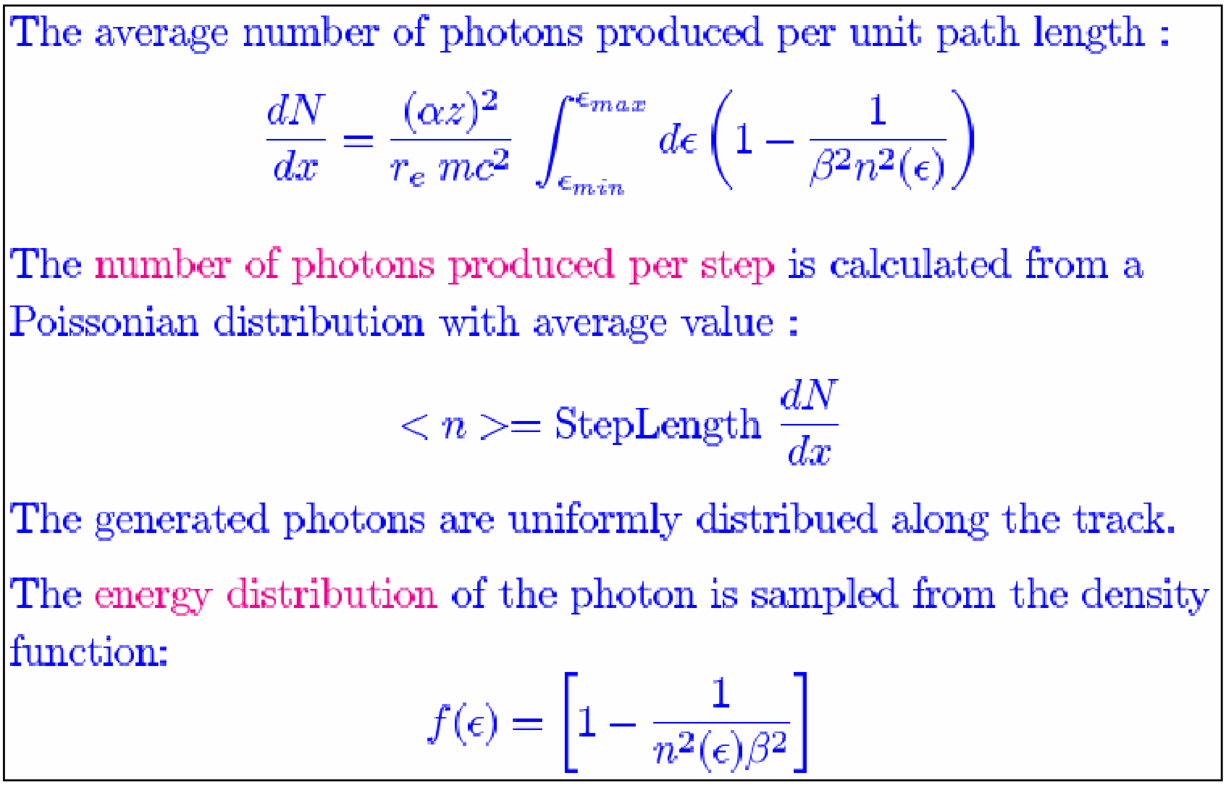
If an incoming 10 TeV dust fall into hundred pieces in the air, the 100 Si ions give the same air shower as the lone 10 TeV particle would give. The quartz grain dust with E=10 TeV loses the electrons with the impact ionization and fall to $^{28}_{14}Si^{14+}$ ions. So it's hard to say that the ground array detectors detect one particle with 10 TeV energy.

The experimental test of this detector type is the following:

The 10^20 eV energies are modeled at SLAC with electron beam. The beam properties: 10^10 electron * 28 GeV/electron what is equal in the model with one 2,8*10^11 GeV particle. The beam target is metal and the secondary electron shower is measured with the “ground” detector.

In **balloon** experiment the measured ionization is the same in the following two cases:
One dust grain with T=10 TeV, Z=8 charge and *mass M=1000 amu* (E=10GeV/amu) has the same ionization in the detector as the T=10 TeV  Z=8 oxygen ion (E=625 GeV/amu) has.
The energy loss is the same within the detector accuracy, because T and Z are the same in the Bethle Bloch formula. The dust grain *impacts* into the detector. The dust loses some electrons, but the dust goes through the detector in a nanosecond. There is no time for further ionization. In gas detector the dust breaks through the detector wall, then moves straight with Z=8 charge. The relativistic “bullet” goes through the silicon and scintillation material, too. And give the same ionization as an assumed 10 TeV particle.
In the ionization measurements everyone assumed that the cosmic ray contain fully ionized ions eg.: $p^{+}$ ,$He^{++}$ .. $^{238}U^{92+}$, and neglected the interstellar dust clouds, molecules and not fully ionized heavy ions: $^{238}U^{2+}$.

The Cherenkov radiation:



The average number of photons produced per unit path length :

$$\frac{dN}{dx} = \frac{(\alpha z)^2}{r_e\, mc^2} \int_{\epsilon_{min}}^{\epsilon_{max}} d\epsilon \left(1 - \frac{1}{\beta^2 n^2(\epsilon)}\right)$$

The number of photons produced per step is calculated from a Poissonian distribution with average value :

$$<n>= \mathrm{StepLength}\ \frac{dN}{dx}$$

The generated photons are uniformly distribued along the track.

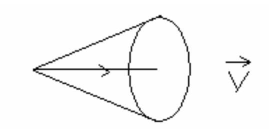
The energy distribution of the photon is sampled from the density function:

$$f(\epsilon) = \left[1 - \frac{1}{n^2(\epsilon)\beta^2}\right]$$

The photon number and photon energy spectrum depend on charge ($Z_p$) and $\beta$ .

But the velocity dependence is negligible on high energies.

The Cherenkov light has the cone angle: $\cos\Theta=\frac{1}{\beta n}$



The angles to the 10 GeV and 10 TeV proton: 12,6 and 13,8 degree.
The angles to the 100 GeV and 1000 TeV proton: 13,85 and 13,862 degree.
So the 100 GeV/amu dust and 1000 TeV/amu particle give the same Cherenkov angle.
And the Cherenkov photon number and photon energy distribution is the same for 10 TeV, Z=8, M=16 amu oxygen ion, and for T=10 TeV, Z=8, *M=1000 amu* dust grain.

## Interaction with Cosmic Microwave Background

$$-\frac{1}{E}\frac{dE}{dt}=\frac{cT}{2\pi^2\Gamma^2}\int_{\varepsilon_{th}}^{\infty}d\varepsilon_r\sigma(\varepsilon_r)f(\varepsilon_r)\varepsilon_r\{-\ln[1-\exp(-\frac{\varepsilon_r}{2T\Gamma})]\}$$

The energy loss depend on microwave temperature (T), the Lorentz gamma of nuclei, background photon energy ( $\varepsilon_r$ ), the cross-section, and mean energy loss (f) in one collision, what contain the impulse invariance of $p+\gamma\longrightarrow p+e^-+e^+$:

$$f_{pair}=\frac{2m_e}{2m_e+m_{nuclei}}$$

All authors use the first Born approximation $m_{nuclei}\longrightarrow\infty$ to get the cross- section. With dust $m_{dust}\approx10^6m_p$ the energy loss and “f” is small. The adiabatic energy loss is described by red shift, Hubble constant, source detector distance (50Mpc<r<800Mpc)[1].

## Dust physics

The initial charge could be positive (+10^-16 C) but mostly negative (-10^-16 C - -10^-10 C). The “slow” accelerator the 3 μG interstellar field can accelerate the dust without ionizing of the dust. A -10^-10 C = 10^6 $e^-$ negative dust can reach 1000 TeV kinetic energy. Then it loses electrons in the interaction with cosmic material, and becomes positive (+10^-16 C). The Si dust can not be very positive, if it loses a lot of electrons with ionization, then one Si ion will separate, and the charge restores about zero. The electron and $Si^{14+}$ ion lose of dust maybe answer the measured cosmic ray charge (peaks are Z=2, 6, 8).

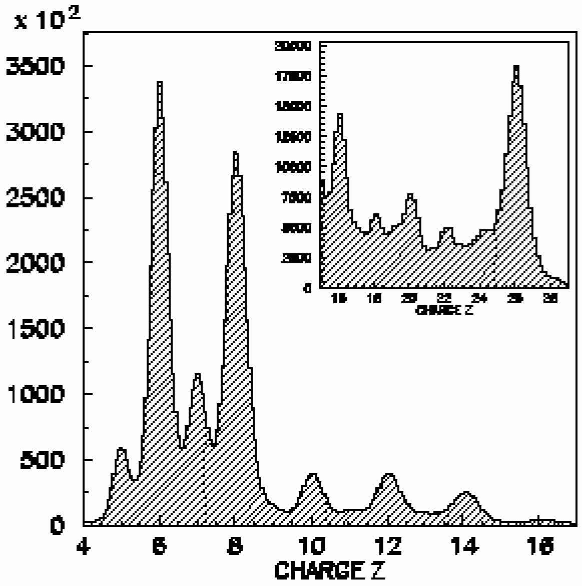
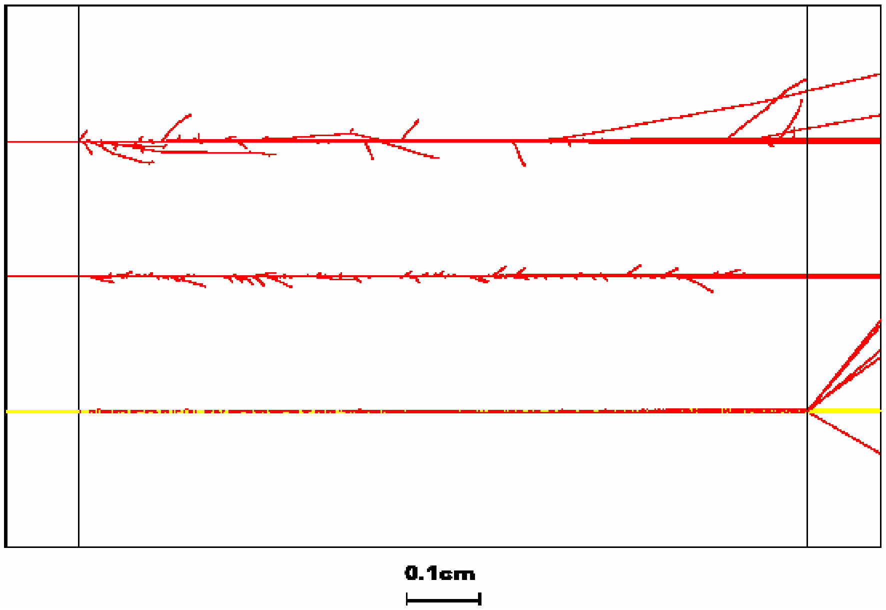


**Figure 2.** Charge histogram for all events measured in flight.

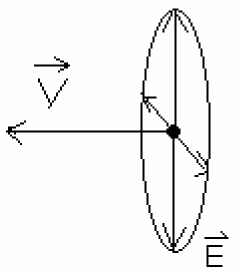
There is no limit of dust kinetic energy. The above TeV particle source is the interstellar magnetic field, which can accelerate the charged dust too. So 100GeV/amu is reachable with the 3 μG interstellar field, but 1000 TeV/amu particle energy is over estimated.

The supernova shocks can't accelerate the dust, because in the high temperature the dust falls into ions. The supernova explosion is thermal plasma; each ion has equal energy (thermal equilibrium). If in the shock would be a microwave acceleration process, then all ion (gigatons) have to reach the 1000 TeV energy, what consume too much microwave energy.

There is some difference when we shot different mass particles into a metal with the same energy. The 2 GeV electron, proton and alpha beam path in Al:



The heavier particles have straight path, so the heavy dust comes straight to the ground thought 30 km air, without scatters.
Relativistic space dust has forward short EM interaction range via Lorentz contraction; opposite the non relativistic dust has sphere symmetrical electrical field.



The elliptical electrical field in the detector coordinate system via Lorentz contraction

TeV particle detector materials are: NaI, Si or gas, the dust material could be anything (CH, Si, diamond, $^{238}U^{++}$...).
The $^{238}U^{++}$ ion is another candidate for the highest energy cosmic ray. It is the heaviest natural element, originates from supernovas, and has the same track in the detectors as the $He^{2+}$.
- To determine the cosmic ray mass, the balloons has to be equip with magnets. First we have to slow down the particle, because we don’t want to measure the relativistic mass $\gamma m$. Then in the magnetic field of the matrix detector the path radius is $R=mv/(ZB)$, which measure precisely the mass.

## Non relativistic dust:

The impact ionization exists only for slow <70 km/s iron dust: $Q \sim mv^{3,5}$
But for 100 GeV/amu dust there is no time for ionization in the detector, the dust take 0,1 nanosecond in the detector with about light speed and lose fewer electron.
Cosmic dust is composed of particles in space which are a few molecules to 0.1 mm in size.
The microscopically dust grain mostly is larger than the size of quantum mechanics.

The planetary dust has low speed (km/s). Then the Bethe-Bloch formula breaks down at low energy ($T_{lim}$<2 MeV/amu). The formula has the following form:

$$\frac{dE}{dx} = \begin{cases} a * \sqrt{\frac{T}{M}} + b * \frac{T}{M} & \text{for } T \in [0, T_0] \\ c * \sqrt{\frac{T}{M}} & \text{for } T \in [T_0, T_{lim}] \end{cases}$$

where : M = particle mass T = kinetic energy, `a,b and c parameters.`
So with the same kinetic energy the heavier particle has the lower energy loss.
- The friction in air is proportional with $T/4\pi r^2$ [joule/barn]

I'm not sure that 10^6 TeV particles have existed in the *flat* Universe in times past. And this energy question became very important, when I proved the cause of Big Bang with superparticles. The superparticles could break the color for a discrete time, and could give infinite color energy. But this theory refutes the >TeV/amu particles in flat space-time cosmic ray.

http://arxiv.org/abs/hep-ph/0510086
http://www.geocities.com/iczovek/Goldstino.pdf

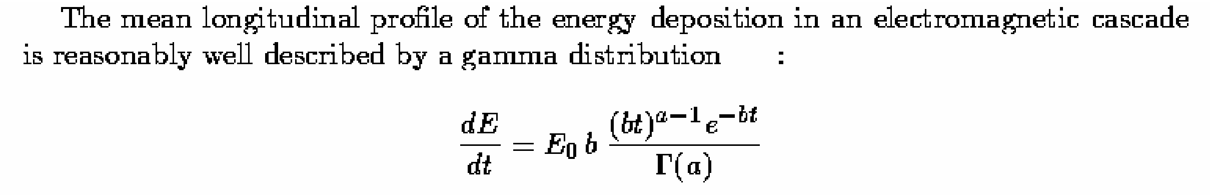
## The cascade process in air

Here we find mass independent processes:
The secondary electron spectra ($\delta$ ray):

$$\frac{d^2N}{dTdx} = \frac{1}{2} K z^2 \frac{Z}{A} \frac{1}{\beta^2} \frac{F(T)}{T^2}$$

Here Z/A is for air, and z is for the primer particle charge. This equation can’t differ particle and dust, if they have the same charge and kinetic energy. The radiation length:

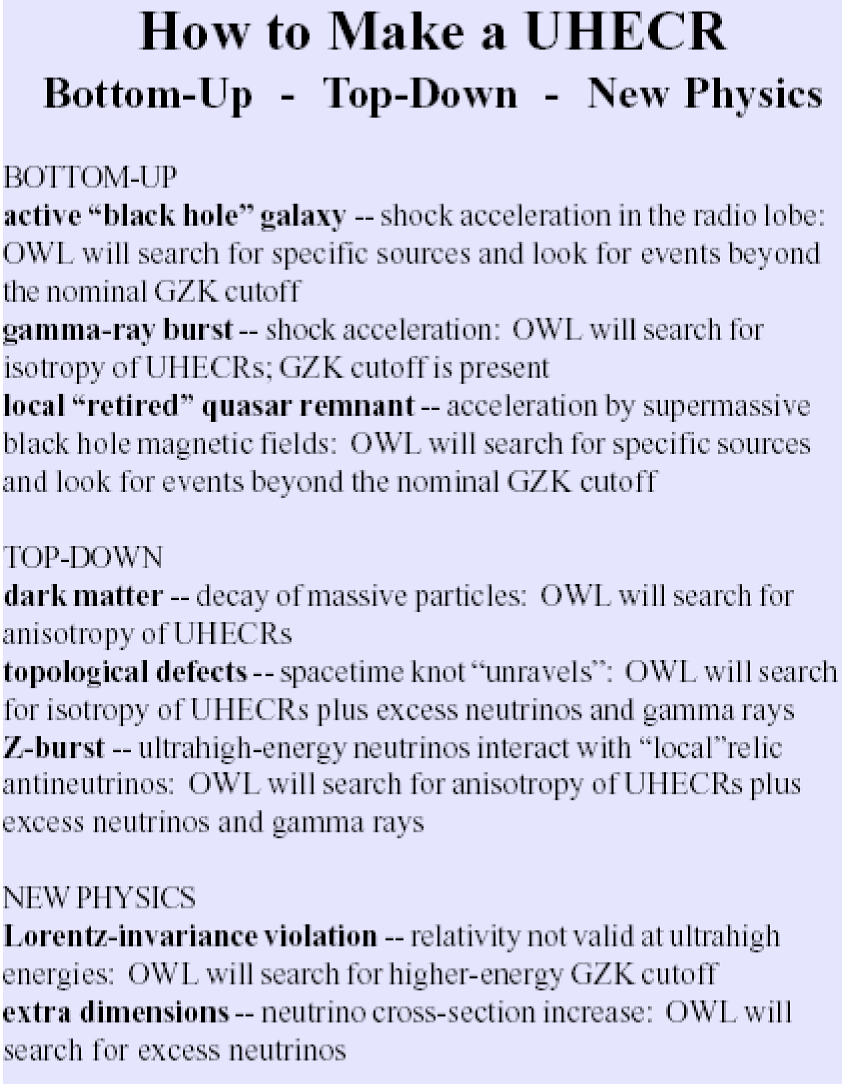
$$X_0 = \frac{716.4 \text{ g cm}^{-2} A}{Z(Z+1)\ln(287/\sqrt{Z})}$$



The mean longitudinal profile of the energy deposition in an electromagnetic cascade is reasonably well described by a gamma distribution :

$$\frac{dE}{dt} = E_0\, b\, \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

Finally the >TeV sources:



## How to Make a UHECR

### Bottom-Up - Top-Down - New Physics

BOTTOM-UP

**active "black hole" galaxy** -- shock acceleration in the radio lobe: OWL will search for specific sources and look for events beyond the nominal GZK cutoff

**gamma-ray burst** -- shock acceleration: OWL will search for isotropy of UHECRs; GZK cutoff is present

**local "retired" quasar remnant** -- acceleration by supermassive black hole magnetic fields: OWL will search for specific sources and look for events beyond the nominal GZK cutoff

TOP-DOWN

**dark matter** -- decay of massive particles: OWL will search for anisotropy of UHECRs

**topological defects** -- spacetime knot "unravels": OWL will search for isotropy of UHECRs plus excess neutrinos and gamma rays

**Z-burst** -- ultrahigh-energy neutrinos interact with "local"relic antineutrinos: OWL will search for anisotropy of UHECRs plus excess neutrinos and gamma rays

NEW PHYSICS

**Lorentz-invariance violation** -- relativity not valid at ultrahigh energies: OWL will search for higher-energy GZK cutoff

**extra dimensions** -- neutrino cross-section increase: OWL will search for excess neutrinos

Ref.:

1. Berezinsky, On astrophysical solution to ultra high energy cosmic rays hep-ph/0204357
2.