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Spectrum of Cosmic Rays Reflects Structure of Space

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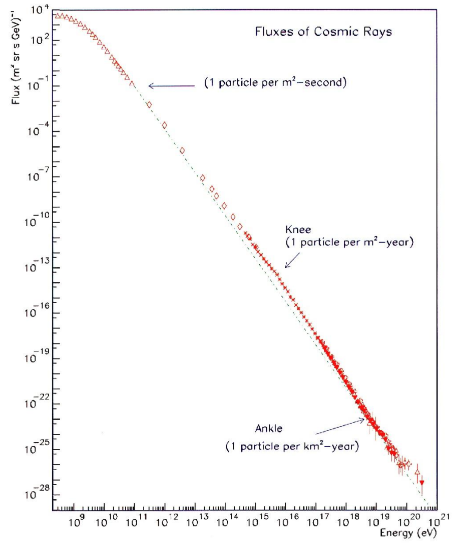
Introduction

Particles, which are known for historical reasons as cosmic rays, impinge on Earth's atmosphere with energies that range over 12 orders of magnitude. As you see their flux vs. energy follows mostly a straight line on the log-log plot, that is, the data complies with a power law, $E^{-\gamma}$. Since the power law is a characteristic of the principle of least action in its original form by Maupertuis, we ought to account also for the spectrum of cosmic rays using this universal imperative.

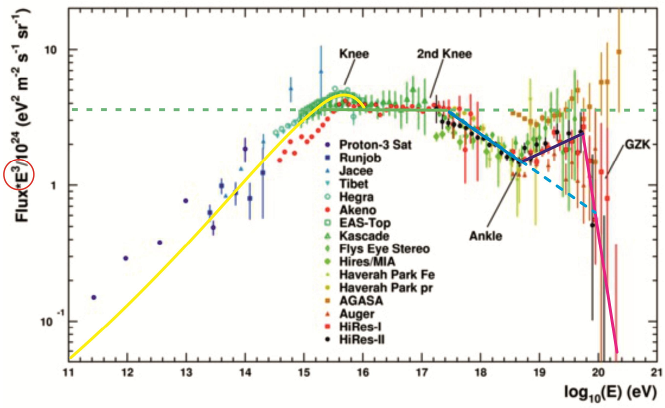


The basic law of nature simply says that *a difference in energy of any kind will be consumed in least time*. So, when a system evolves along its least-time path, the conservation of quanta requires that a change in kinetic energy equates changes in scalar and vector potentials, $d_t 2K = -\mathbf{v}\cdot dU + d_t Q$. In general the least-time consumption of free energy results in a sigmoid curve whose central power-law region dominates on the log-log scale where an initial start on and a final finishing off appear as contracted.

In a particular case when the system has already attained a free energy minimum stationary state, that is, experiences no further changes, and hence, there is no net dissipation to the surroundings, the integrated equation of motion yields the familiar virial theorem, $2K + U = 0$. Such a steady-state partition of sources produces a flux that falls as one over the cube of kinetic energy $1/E^3$.

Stationary flux

So, when the observed flux is multiplied with E^3, a stationary system can be spotted where the data is flat. The particles in this range from some million Giga electron volts to about billion Giga eV arrive to us unaffected from sources in the nearby non-expanding part of the Universe such as our nearest galaxies.



High-energy flux

At higher energies the flux falls more rapidly than $1/E^3$. It means that the kinetic energy of particles exceeds the source potential of these sparse surroundings where we detect them. Therefore the high-energy particles that are primarily protons will slow down first by producing pairs of electrons and positrons as vortices from the photon-embodied surrounding vacuum. And then at even higher energies the protons will decelerate even more effectively by producing pions as wakes from the photon-embodied surrounding vacuum.

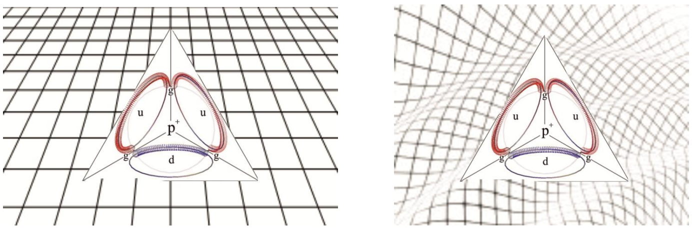
The decelerated protons will, of course, pile up at lower energies, and hence contribute to the flux below the on-set energy. The proton pile-up is particularly pronounced for the pion production, but hardly noticeable for the less effective electron-positron pair production. The on-set energies of the two processes relate to each other by the meson-lepton mass ratio. Their relative rates should also relate to each other by the mass ratio, but this is difficult to assess from the data with large experimental uncertainties and with apparent difficulties in calibration. Nevertheless, the integrated pile-up gives us an estimate of the flux' final cut-off energy.

The rates via these mechanisms, as the rates of all least-time mechanisms, are proportional to the free energy, and hence the flux across the energy scale compiles from sections of straight-lines when plotted on the log-log scale where the sigmoidally rounded intersections appear very short.

The meaning of mass

How do the protons ever acquire such high energies that correspond to a baseball hit by a professional player? Recent observations imply that the ultra-high-energy protons originate from supermassive black holes at centers of nearby galaxies. However, the precise mechanism of proton acceleration to these extreme velocities remains a puzzle.

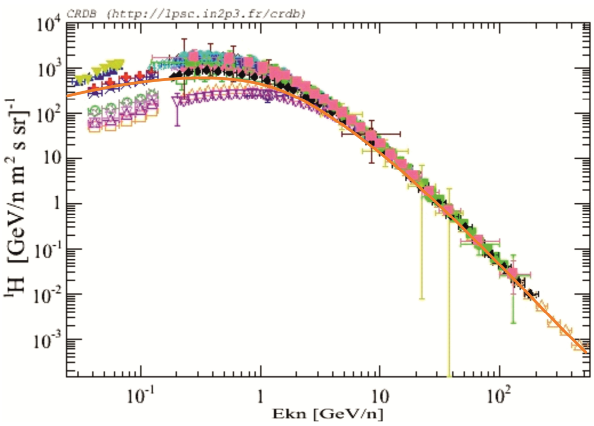
Therefore it is worth pointing out that the mass of a particle, as Euler already defined it, quantifies the geometry of particle's quantized action *in relation* to the geometry of freely propagating actions that embody the surrounding space. In other words the mass is not an invariant, but depends on the surrounding curvature. So the ultra-high energy protons will strike our detectors, because the mass will increase on the way from the high-density curved nascent ambiences in an active galactic nucleus to the low-density flat surroundings of our observatories.



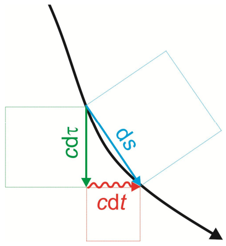
Cosmic flux

At energies below the stationary $1/E^3$-region the flux falls less rapidly. The total source potential exceeds the kinetic energy since the particles originate both from the nearby stationary sources and from receding sources in the expanding part of the Universe. Obviously, the particles must have departed at higher energies than those we measure at their arrival to compensate for the sources' recessional velocities. So, although there are more and more receding sources within the increasing radius of integration, fewer and fewer of them are energetic enough to launch particles to those high speeds for them to arrive at the observed kinetic energy.

Below about one million Giga electron volts the integrated flux from the expanding part of the Universe becomes first comparable to the flux that originates from the nearby non-expanding space. At lower and lower energies, now displayed on the log-log scale without multiplication by E^3, the flux increases with increasing radius of integration at about a constant rate until the kinetic energy begins to approach the rest energy of proton whereabouts the flux attains its maximum. The rate will decrease with decreasing energy because the arrival rate is approximately proportional to the kinetic energy. And soon the flux will turn down since obviously in the limit of a particle being at rest, it cannot arrive to our detectors.



In the calculation of the flux vs. kinetic energy the familiar Lorentz factor $\gamma = \mathrm{d}t/\mathrm{d}\tau = 1/\sqrt{1 - v^2/c^2}$ comes in hand. It is obtained from the least-time imperative in the limit of Euclidean continuum where an infinitesimal change in the kinetic energy $d(2K) \to \mathrm{d}s^2$ equates infinitesimal changes in the potential energy $\mathrm{d}U \to c^2\mathrm{d}\tau^2$ and in the dissipation $\mathrm{d}Q \to c^2dt^2$.



Gravitational force as an energy density difference

Earlier the various sections of the cosmic ray spectrum have been modeled piece by piece with power laws in a phenomenological manner, but now we have founded all of them on one and the same universal principle of least action and associated each region of the flux with a characteristic mechanism of free energy consumption, and thereby narrowed the number of adjustable parameters.

In particular we identify the border zone between the expanding remote Universe and the practically stationary nearby part of the Universe from the computed flux for the receding sources to be at a distance of about 1 Mpc in agreement with astronomical observations. In this intriguing zone of delicate thermodynamic balance energy densities among the bodies and their surroundings are comparable to each other. The little excess in the flux, seen as a hump above the stationary flux, results from those sources that are just barely floating away from us before the Hubble flow really sets in.

In this context it is worth emphasizing that the reason both for the expansion and contraction is the same, namely, the difference between the energy density within the system of bodies and the energy density in the photon-embodied surrounding space. It is only the sign of this energy density difference that dictates whether the bodies will be moving toward each other or away from each other. In other words gravity, like any other force, should be regarded, not merely as an attractive force, but likewise as a repulsive force when the surrounding density exceeds the density within the system of bodies. For example, right here on Earth the surrounding energy density in the form of stored sunlight is, as you witness, sufficiently high to move my laser pointer away from the ground.

Conclusion

So all in all, you have seen how the supreme law of nature allows us to interpret the cosmic ray spectrum over its huge range of energies to report from the structure of the space ranging from gigantic cosmic spans down to its microscopic photon-embodied vacuum.

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