Radboud Universiteit Nijmegen
Afdeling Sterrenkunde
Jörg R. Hörandel
Antonio Bonardi

Astroparticle Physics – 2015/16

Werkcollege 13 – 14.12.2015

Problem 46 High-energy gamma rays

List the most common production mechanisms for high-energy gamma rays (photons with energies exceeding 100 MeV).

What means Synchrotron Self Compton (SSC)? Sketch a typical spectrum of a high-energy gamma-ray source in which SSC plays an important role.

Problem 47 Gamma-ray detection by IACTs

Gamma rays interacting with the Earth's atmosphere produce a pure electromagnetic cascade in the atmosphere, which can be quite well described by Heitler's model (see also Problem 32). All charged secondary particles in the cascade will produce Cherenkov light during their propagation through the atmosphere. As consequence, a Cherenkov circle with radius of about 1° will be projected on the ground. The Cherenkov light can be detected by an Imaging Atmospheric Cherenkov Telescope (IACT), if located within the Cherenkov cone.

a) By assuming that the Cherenkov light intensity is homogeneous within the Cherenkov cone (circle on the ground) and considering an air shower initiated by a photon, impinging vertically onto the atmosphere with an energy $E = 1$ TeV, compute the amount of photons collected by an IACT with a circular collecting area ($R_{dish} = 6$ m), located at 1800 m above sea level (a.s.l.) with an overall Cherenkov photon detection efficiency equal to 10%.

Hint: assume that the Cherenkov emission is generated around the shower maximum X_{max} and assume X_{max} being at 10 km a.s.l. Neglect any absorption of the Cherenkov light by the atmosphere. Use the formula

$$\frac{dN}{dx} = 380 Z^2 \sin^2 \Theta \text{ photons cm}^{-1}$$

(see Problem 35) to calculate the number of Cherenkov photons emitted by each electron/positron, where Θ is the Cherenkov light emission angle and the air refractive index around X_{max} is $n_{air}^{X_{max}} = 1.0002$. Assume that all the electrons/positrons travel the same distance X_0 equal to 36.66 g cm^{-2} (corresponding to ~ 700 m at 10 km a.s.l.).

b) Assuming the same extensive air shower, estimate the number of particles reaching the ground.

Hint: use Heitler's model to compute X_{max} and N_{max} and use the Gaisser-Hillas formula

$$N(X) = N_{max} \left(\frac{X - X_{first}}{X_{max} - X_{first}} \right)^{\frac{X_{max} - X_{first}}{\lambda}} \exp\left(\frac{X_{max} - X}{\lambda} \right)$$

to compute the number of particles at ground level (1800 m a.s.l. corresponds to $X = 840$ g cm^{-2}).

Problem 48 IACTs working in an array

IACTs are nowadays operated almost exclusively within an array of telescopes. At present, the H.E.S.S. experiment has 5 working IACTs in Namibia, VERITAS 4 IACTs in Arizona (USA), and MAGIC 2 IACTs at the Canary Islands (Spain). The Cherenkov Telescope Array (CTA) project is an international initiative, aimed to build the next generation ground-based very high-energy gamma-ray observatory. It will consist of over 100 telescopes of three different sizes, placed on two arrays, one in the Northern the other in the Southern Hemisphere, to cover the full sky (for more details see the website *www.cta-observatory.org*).

The big advantage of having IACTs working together in an array is that this enhances the overall IACT performances (energy threshold, energy resolution, direction resolution, etc.), without requiring to enhance the single telescope properties.

By considering the same air shower and the same IACT of Problem 47, and assuming that at least 100 Cherenkov photons must be detected to trigger an IACT, compute the energy threshold a stand-alone IACT.

If 2 IACTs are within the Cherenkov cone, we can assume the amount of Cherenkov photons required to trigger each IACT is reduced to 25. Compute the new energy threshold.

Problem 49 Hadron-lepton discrimination on satellites

Hadrons (i.e. manly protons) and leptons (i.e. electrons/positrons) are discriminated in space-born detectors by observing how they interact inside a calorimeter. One of the used observables is the geometric development of the cascade. Electrons produce an almost pure electromagnetic cascade, whose shape is symmetric to the propagation axis and most of the energy is released along the propagation axis; protons produce mainly hadronic interactions and the energy release is much more spread inside the calorimeter (see Heitler's model and Problem 33) without any symmetry. Nevertheless, there is a residual probability P_{π^0} that, during the first hadronic interaction, an electromagnetic cascade is generated (through π^0 decay) and that cascade overwhelms the tracks of all the other hadronic cascades. The second used observable is the depth where the impinging particle has its first interaction. While the interaction length for protons is approximately equal to 90 g cm^{-2}, the interaction length for electrons is given by the formula (see Problem 9)

$$X_0 = \frac{716\ A}{Z(Z+1)\ln\left(287/\sqrt{Z}\right)} \text{ g cm}^{-2}$$

Therefore, on average, protons will interact deeper in the calorimeter than electrons.

Given an abundance ratio

$$R = \frac{N_{e^-}}{N_p} = 10^{-3}$$

and a residual probability of $P_{\pi^0} = 0.2\%$, compute the geometric thickness inside a calorimeter made of Tungsten (A = 184, Z = 74, ρ = 19.25 g cm^{-3}) for which the percentage of proton contamination in the detected electron-like particles is equal to 10% (i.e. every 10 detected electron-like particles 1 is not an electron but a proton).

Hint: remember that for a generic particle crossing a medium the survival probability is equal to

$$P(x) = e^{-\frac{x}{\lambda}},$$

where λ is the particle interaction length.

The solutions will be discussed during the werkcollege on 14.12.2015 in HG03.082.
Student assistant: Antonio Bonardi a.bonardi@astro.ru.nl
Lecture web site: http://particle.astro.ru.nl/goto.html?astropart1516