Exercises (2)

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2 Sensitivity of Cherenkov Telescope Arrays

2.1 Effective area

Provide a crude estimate (order of magnitude) of the effective area A_{eff} of a system of 4 Cherenkov Telescopes located at the vertices of a square of side equal to 120 m. To do so, remember that a very-high-energy gamma-ray photon generates a shower of particles in the atmosphere. For photon energies in the TeV domain, The Cherenkov light emitted by such particles invests an area of ground of radius equal to ≈ 120 m.

2.2 Flux sensitivity

The Crab nebula is among the brightest gamma-ray sources in the sky. It is a point source of TeV photons, so its apparent size is equal to the point-spread-function of the array of Cherenkov telescopes, which is typically of the order of 0.1 degrees. Its flux at Earth, for photon energies larger than $E_\gamma = 1$ TeV, is:

$$\Phi_\gamma(> 1 \text{ TeV}) \sim 2 \times 10^{-11} \text{photons cm}^{-2}\text{s}^{-1} \qquad (1)$$

Compute:

1. the rate R_s at which photons from the Crab with energies above 1 TeV are detected by the array;
2. the rate R_b at which cosmic rays with energy in excess of 1 TeV are detected by the array from the position of the Crab (use the results from exercise 1);
3. how long it takes to detect the Crab? (remember that from the shape of the image of the shower, it is possible to reduce the cosmic ray background by a factor of $\eta_{CR} \sim 10^{-2}$)
4. the minimum flux detectable by the array for a long observation time of $T = 50$ hours.

3 The gamma ray luminosity of the Milky Way

Use the results from exercise 1 to compute the gamma-ray luminosity of the Milky Way above ~ 1 TeV. The average gas number density of the interstellar medium is ~ 1 cm^{-3} and the confinement time of ≈ 10 GeV cosmic rays in the Galactic disk is ~ 3 Myr. Compute then the maximum distance up to which a galaxy identical to the Milky Way would be detected by an array of Cherenkov telescopes such as that described in exercise 2. Comment the result.

4 Supernova remnants and dimensional analysis

Derive the scaling between the shock radius R_s of a supernova remnant and its age t by using dimensional analysis. Express the scaling as $R_s = A\ t^{\alpha}$ and find the values of A and α for:

1. a remnant in the energy conserving (Sedov) phase;
2. a remnant in the radiative (snowplough) phase;
3. a remnant in the momentum conserving phase;
4. a remnant in the energy conserving phase, under the assumption that the density of the interstellar medium surrounding the position of the explosion is not spatially uniform, but scales as $\varrho = B\ R^{-2}$. Here R is a radial coordinate and represents the distance to the centre of the explosion ($R = 0$).