Astroparticle Physics

Evaluation component

Date : 12th to 20th December 2022

1. Observers living in a planet within another galaxy in our Universe have measured a flux of charged cosmic rays from 1 GeV to 10^{12} GeV. The astronomers there report that their star is about 6 kpc away from the centre of the galaxy, while the galaxy itself is twice the diameter of the Milky Way.
    a. The flux of cosmic rays become steeper at ~25 PeV, with the spectral index changing from 2.7 to 3.1 sigma over the next 10 PeV. What is the average strength of the magnetic field within their galaxy? **(13 marks)**
    b. The flux of Cosmic Rays they measure is found to have a normalization corresponding to $10^{11} m^{-2} sr^{-1} s^{-1} GeV^{-1}$ at an energy of 1 PeV. What is the rate of supernova explosions within their galaxy? **(12 marks)**

2. The Cubic Kilometre Neutrino Telescope, or KM3NeT (https://en.wikipedia.org/wiki/KM3NeT) , is a future European research infrastructure that will be located at the bottom of the Mediterranean Sea.
    a. Describe the conditions required within the detector to trigger data acquisition to disk (according to current design specifications), and the corresponding event rate. **(7 marks)**
    b. Calculate how the event rate will change if
        i. The distance between the DOMs is varied, between x/10 and 3x, where x is the present (i.e design) distance between the DOMs **(9 marks)**
        ii. If the time window for which the trigger conditions are applied is doubled. **(9 marks)**

3. NGC1068 is a nearby Active Galactic Nucleus from the direction of which an excess of neutrinos has been reported at 4.2σ statistical significance, using 9 years of iceCube data (https://inspirehep.net/literature/2176154).
    a. Assuming that the best fit flux and spectral index for the source in the above paper is the true flux and spectral index, what will be the statistical significance of the source after 15 years of operation? **(10 marks)**
    b. Data from the MAGIC IACT telescope have been used to provide constraints on the neutrino flux from this source (https://arxiv.org/pdf/1906.10954.pdf). Are these constraints compatible with the IceCube measurement? If not, how big is the discrepancy? Which assumption that goes into the prediction will you revisit? **(15 marks)**

4. The highest energy cosmic ray ever observed (which was named the Oh-My-God Particle, really, look it up on Wikipedia) had a recorded energy of 3.2 × 10^{20}eV.
    a. What is the mean free path for a proton of this energy, assuming collisions with the Cosmic Microwave Background photons? **(15 marks)**
    b. How far away could this particle have come from? Do you believe this measurement? **(10 marks)**