PHYSICS 313 - Winter/Spring Semester 2017 - ODU

Astrophysics - Problem Set 8 – Solution

Problem 1

Mark each of the following statements with "Y" or "T" if they are correct, and with "F" or "N" if they are incorrect:

1a) Gravitational Waves are too weak to ever be detected. **F**

1b) Every single elementary particle predicted by the Standard Model *) has been found. **T**

1c) The Standard Model can explain every astrophysical observation to date. [Not dark matter, dark energy or inflation.] **F**

1d) Gamma rays cannot be detected directly by satellites. [In fact, satellites are the only way to see gamma rays directly!]] **F**

1e) Gamma rays can be detected by ground-based observatories that look at their interaction with the atmosphere. **T**

1f) Atomic nuclei are made of quarks. **T**

1g) Some cosmic ray telescopes have observed single, isolated quarks from some cosmic source. [No: quarks always appear bound inside hadrons like protons or pions] **F**

1h) Very high energy cosmic rays require fundamental particle detectors to be "seen". **T**

1i) Most high-energy cosmic rays originate from our sun. [No, from supernovae or black holes] **F**

1j) There is an upper limit to the energy of protons that travel over long distances (of the order Megaparsecs). [Because of inverse Compton scattering off the CMB radiation] **T**

1k) No neutrinos from outside the solar system have been detected yet. **F**

Problem 2

The following is a set of multiple choice questions. Answer each with one single digit:

2a) Which of the following types of "cosmic rays" can NOT "tell" us where they might have originated in the Universe? **3**

1 – Photons
2 – Neutrinos
3 – Protons up to a few thousand GeV energy
4 – The most energetic particles ever observed.

2b) Which of the following particles can change their type (oscillate in flavor) in flight? **2**

1 – Photons
2 – Neutrinos
3 – Protons
4 – Positrons

---

*) In this problem, the term "Standard Model" refers to the present standard model of particle physics, which includes all fundamental matter particles and their interactions except gravity.

2c) Which of the following properties do neutrinos have in common with electrons? **3**

1 – Their masses [No; all neutrinos are lighter than the electron]

2 – Their electric charges. [No, neutrinos have zero charge, and electrons have -1 *e*]

3 – Their spin [Yes, both carry spin ½]

4 – Their interaction cross section with matter [No: neutrinos only interact via the weak force and gravity, while electrons also interact electromagnetically which leads to a much higher cross section].

2d) Which of the following properties do gauge bosons have in common with quarks? **1**

1 – Some have rather large masses [Indeed, the heaviest known gauge boson - the Z^0 - has a mass of about 90 GeV, while the top quark is about twice that.]

2 – Their electric charges [No: quarks carry fractions 1/3 or 2/3 of the elementary charge, while gauge bosons only carry 0 or 1 elementary charge.]

3 – Their spins [No: Gauge bosons all have spin 1, while quarks have spin ½]

4 – They can be produced one at at time in certain reactions [No: quarks can only produced together with anti-quarks, while gauge bososn can be produced without partners]

5 – They can interact directly with each other, without an intermediary [Some gauge bosons can directly interact with other gauge bosons, e.g. photons with W^+ and gluons with each other, while quarks require gauge bosons to interact with each other].

Problem 3

So far, cosmic rays consisting of protons, nuclei, leptons (and some antileptons), neutrinos and all kinds of electromagnetic radiation (photons) have been detected and studied. Give at least one example for a particle or cosmic ray type that has not yet been observed directly (and unambiguously) and that is not part of the Standard Model, but has been conjectured or predicted to exist by some theorists. Explain in at least 5-10 sentences why the particle is thought to exist, what its presumed properties are, and how scientists are hunting for such particles.

Answ.: We know that the universe must be filled with an unknown substance called “dark matter” – in fact, it makes up the vast majority of all mass. One of the leading contenders for this dark matter are neutral, weakly interacting massive particles (“WIMPs”). In turn, many physicists believe that these WIMPs could be the so-called “supersymmetric partners” of existing neutral particles (neutralinos), e.g. the partner of the Z boson (“Zino”). Therefore, many experiments are looking actively for these particles – which is difficult, since they interact only weakly. Most “dark matter detectors” are based in deep underground labs (to shield more ordinary cosmic ray background) and try to detect the recoil atoms from interactions between the detector material and the (putative) WIMPs. There are also attempts do use space-based detectors to look for possible decay products of WIMPs or their interactions with ordinary matter. Finally, there is a big program underway at the European Accelerator Center “CERN” to produce and detect supersymmetric particles in the Large Hadron Collider (LHC). If confirmed, supersymmetry is an extension of the standard model of particle physics which will double the number of fundamental particles.

There are other, even more speculative particles that may exist but haven’t been found yet – so-called axions, or heavy partners of the photon, sterile neutrinos etc. People are looking for them, but no guarantee that they will ever be found.

Another type of particle not yet found is the graviton. On the one hand, we now know that gravity waves exist – as predicted by General Relativity and previously inferred from the motion of double-pulsar systems. These waves are basically ripples in space-time which lead to elongation and compression (by tiny amounts) of all matter in their way. There are several gravity wave detectors in operation on Earth (including the twin LIGO detectors which made the first observation of these waves). They use interferometry with several km long arms and high precision optics to detect the resulting compression of space down to the level of a fraction of a nuclear size. Gravity has not yet been successfully incorporated into the Standard Model (since it doesn't mesh well with quantum mechanics), however most ideas for such a unification involve gauge bosons with spin 2 called gravitons. Gravity waves can be considered manifestations of these gravitons –analog to photons in light waves. However, it would be a stretch to say that detecting gravity waves is the same as detecting gravitons - a direct detection is still a long way off given how feebly they interact and how hard it would be to produce a significant number of them.