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P4_12 Mirror, Mirror

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Abstract

The existence of mirror matter is explored as a possible solution to the lack of conservation of parity in particle interactions. Ways in which this matter would present itself in the universe are discussed, as are possible methods for observing it in order to confirm or deny its existence. It is found that it is possible for mirror matter to be indirectly observed, but not necessarily recognised.

The $\theta\tau$ Puzzle

In the mid-1950's, during the sudden abundance of new particle discoveries, it was found through experimental data [1] [2] that two mesons (θ^+ and τ^+) had been measured to have incredibly close masses and lifetimes. It would be suggested that they are the same particle but for one major problem: their different decays.

$$\theta^+ \rightarrow \pi^+ + \pi^0$$
$$\tau^+ \rightarrow \pi^+ + \pi^+ + \pi^- \qquad (1)$$

It is known that the decays of particles must follow conservation laws (such as the conservation of energy, charge, etc.) The decays seen in (1) violate the conservation of parity, where a parity transform is simply

$$(x, y, z, t) \rightarrow (-x, -y, -z, t). \qquad (2)$$

Since the resulting parities were different, it was assumed that the original particles' parities must be different, so they could not be the same particle – this became known as the $\theta\tau$ puzzle. It was solved in 1956 by Lee and Yang [3] through the hypothesis that weak interactions between particles do not always have to conserve parity, and this was confirmed experimentally in 1957 [4]. However, this only shifts the problem: how is it that only the property of parity can break during particle interactions?

Mirror particles

If we consider the parities of particles to be an intrinsic "left-" or "right-handedness" then an obvious solution to the parity violation presents itself: the creation of a whole new set of particles so that for each right-handed particle there is an identical left-handed one. These became known as mirror particles, and would restore the global symmetry of parity.

Since ordinary particles (O-particles) are identical to mirror particles (M-particles) in every way but one, they are very weakly interacting with O-particles. It is this property that has allowed M-matter to become a possible candidate for dark matter [5].

A Mirror Universe

By considering the properties of M-matter at the inflationary stage of the universe, it can be predicted how it behaves on a cosmological scale. Using these predictions, possible experiments designed to confirm or deny the existence of M-matter can then be devised. It has been shown [5] that M-matter does not interact with O-matter using any of the fundamental forces of nature except gravity; this gives rise to the possibility of the formations of cosmological structures such as M-stars, M-planets, or even M-galaxies.

One way an M-star could be observed directly is by giving off O-photons, which could be achieved through the gravitational accretion of O-matter onto an M-star. If we assume that the kinetic energy of the accreting matter is converted to electromagnetic radiation, then the accretion luminosity can be found to be [6]

$$L \sim \frac{GM\dot{M}}{R}, \tag{3}$$

where G is the gravitational constant, M and R are the mass and radius of the stellar object, and $\dot{M}$ is the mass accretion rate. The emitted radiation can be estimated using [6]

$$\left(\frac{L}{4\pi R^2 \sigma}\right)^{1/4} \lesssim T_{rad} \lesssim \frac{GMm_p}{3kR}, \tag{4}$$

where σ is the Stephan-Boltzmann constant, m_p is the mass of a proton, and k is Boltzmann's constant. Eq. (4) shows that the temperature of the star is estimated to lie between the temperature due to radiating as a blackbody, and the temperature of turning all of the star's gravitational energy into heat. We shall assume the star to be a mirror neutron star, since this will give one of the largest energy outputs. For a solar mass star, with a radius of around ~10^4m, the accretion luminosity is found to be ~10^{34} erg s^{-1} (with an accretion rate of ~10^{14} gs^{-1} [7] – a typical value for an accreting neutron star) so the limits given by Eq. (4) are

$$\sim 2 \times 10^6 \mathrm{K} \lesssim T_{rad} \lesssim 5 \times 10^{11}\ \mathrm{K}.$$

Using [8]

$$E_{rad} = k\, T_{rad} \tag{5}$$

this gives the energy emitted as

$$\sim 200\ \mathrm{eV} \lesssim E_{rad} \lesssim \sim 43\ \mathrm{MeV}.$$

This shows that the emitted radiation would be between gamma and extreme ultraviolet, but due to the nature of the assumptions it can be seen that it is a very large range, so therefore a very rough estimate. Also, there is nothing in the calculations that would differentiate the emissions of an accreting O-star from an accreting M-star.

Conclusion

The existence of mirror particles is postulated as a solution to the symmetry of the parity problem. It is found that it would be possible to indirectly observe stellar objects made from mirror matter if they accreted ordinary matter fast enough to be luminous, but this would not necessarily mean that the stars are recognised as M-stars. Also, the calculations in this article are for an accreting neutron star – this is one of the most likely stellar bodies to be luminous due to the mass/radius ratio and the high mass accretion rate, so other stars would be less likely to be observed. Perhaps further research into the area would reveal recognisable differences between observed accretion discs on M-stars, and those on O-stars.

References

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