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1964

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Abstract

Based on the asymmetry of gravitational radiation with respect to positive and negative mass, a physical process is proposed whereby negative mass could be generated inside certain celestial objects. This process could then account for the prodigious amounts of energy radiated by the recently-discovered quasi-stellar radio sources, it could remove a difficulty connected with their rapid fluctuations in brightness, and could provide an alternative to the synchroton theory of the continuous spectrum of their emitted radiation. It could also account for the existence of cosmic ray showers of extremely high energy.

Negative Mass as a Gravitational Source of Energy in the Quasi-Stellar Radio Sources

by

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Negative mass may or may not exist. If it does, then according to both Newtonian mechanics and Einstein's general theory of relativity, it behaves in a most astonishing manner. For example, by the principle of equivalence the ratio of gravitational to inertial mass must be positive for all mass. Therefore, as is well known, positive mass attracts negative as well as positive mass, while negative mass repels both types of mass. Consequently, if a mass +m is placed near a mass -m, the two move in the same direction with ever-increasing speed, the negative mass chasing the positive. At first this seems to contradict the law of conservation of energy. But the particle of negative mass acquires negative energy as its speed increases, and the total energy of the two particles remains constant.

So disconcerting is the behavior of negative mass that when Dirac discovered the negative-mass solutions of his relativistic equations of the electron he was dismayed. But by imagining almost all of the negative energy states filled, he was able to treat the occasional vacancies as particles of positive mass and positive charge, thus arriving at the concept of anti-matter. Anti-matter is now treated as having positive mass in its own right rather than as being an absence of negative mass.

We propose here to take the idea of negative mass seriously, a major reason for doing so being the desperate theoretical situation into which physics has been thrust by the anomalous behavior of the recently-discovered quasi-stellar radio sources.[1] The idea of negative mass is extremely natural in the general theory of relativity. Indeed, one can exclude negative mass from Einstein's theory only by an *ad hoc* assumption extraneous to the theory.

According to Einstein's theory, gravitational waves are theoretically possible. It may well be that they are not generated by bodies in free fall; but if they exist they should be generated when matter is strongly influenced by non-gravitational forces. In the special cases that have been studied,[2] these waves carry away energy and cause a corresponding diminution in the mass of the radiating body. But there is a peculiar asymmetry about the energy transported by the gravitational waves: the energy is positive whether the mass of the source is positive or negative. Since this apparently arises from the Minkowskian signature of space-time it would seem to be of a fundamental nature. It has significant consequences. For unlike electromagnetic waves, which do not transport charge though their source is charge, gravitational waves are produced by mass and transport mass (in the form of energy). So if a body of mass m gives off gravitational waves of energy $c^2\Delta m$, its mass is reduced to $m - \Delta m$, but if the mass of the emitter is $-m$ it becomes $-(m+\Delta m)$, which is a *greater* amount of negative mass than before.

Let us assume that there is a quantum law, analogous to the law of conservation of baryon number, that prevents particles of positive rest mass from decaying into particles of negative rest mass. And let us assume that under extreme and unusual conditions such as might occur inside the quasi-stellar radio sources, *and only under such conditions*, the law is violated, so that "forbidden" transitions can occur, these transitions being linked to the weakest known interaction, gravitation, and requiring the emission of gravitational quanta of positive energy.

Consider what might happen near the center of an extremely hot and massive celestial object. The high pressure and temperature will subject particles there to intense nuclear forces which, being non-gravitational, could cause strong emission of gravitational radiation. Particles of positive rest mass emitting gravitational quanta of sufficient size will turn into particles of negative rest mass; and further emission by these particles will only increase the amount of their negative rest mass. Some of the gravitational radiation may be reabsorbed by matter of negative rest mass, but much of it will escape to the less central regions of the celestial object where conditions do not favor such transitions, and there it will undergo "Compton" collisions, giving up energy that will ultimately be converted to electromagnetic and other radiation.

Since negative masses react perversely to all except gravitational forces, they will be less buoyant than positive masses.* But negative mass is self-repelling. So, as it accumulates centrally, it will tend to cause instability, and part of it may ultimately escape from the quasi-stellar objects in eruptions that could be the cause of the characteristic jets associated with some of these objects.

It is precisely because the quasi-stellar objects emit amounts of energy so prodigious as to defy conventional explanation that the cconcept of negative mass deserves to be taken seriously. For when negative mass is produced within such objects positive energy is made available, and the greater the amount of negative mass created, the greater the amount of positive energy released. Nor need positive mass always be used up when such energy is released; for if a particle of negative mass is sufficiently accelerated it can radiate further gravitational quanta, thus sending out more positive energy while falling to a yet lower negative energy state. (Since the inertia increases, the process need not diverge.) The violet shift caused by the negative mass will be negligible compared with the Hubble shift. Moreover, should any negative mass escape, whether in a jet or less spectacularly, the quasi-stellar object will merely be left with greater positive energy than before. Thus the mechanism outlined here could well account for the extraordinary flux of energy from these objects.

The electromagnetic radiation ultimately generated in the

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*I am indebted to Dr. Ivor Robinson for this remark.

charged outer layers by the gravitational radiation would have a wide range of frequencies, and this could account for the remarkable intensity observed in the radio region.* Again, puzzlement has been expressed over the fact that the brightness of some of the quasi-stellar objects fluctuates with a period very much smaller than the time needed for light or any other influence to traverse the object. But if gravitational waves whose intensity fluctuates with the observed period were generated in a small central region, they could ultimately trigger simultaneous changes in brightness of the observed period in large spherical outer layers of the objects.

What happens to particles of negative mass that escape? They are unlikely to be present in interstellar space in sufficient amounts to affect significantly our estimates of the average density of the universe. Since they repel all matter, they cannot form negative-mass stars. If the universe is such that negative-mass particles can, on balance, "escape to infinity" there will be an effect of continual creation of positive energy in the observed region.

Since negative mass is not antimatter, a charged particle of rest mass -m meeting a particle of rest mass +m and the same (not opposite) charge could form with it a stable, loosely bound system whose mass would be merely that of the electromagnetic binding energy. Such an entity would acquire enormous speeds in extended intergalactic

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*The observed polarisation is small, and it neither rules out the proposed mechanism nor confirms that synchroton radiation is a major component.

fields too weak to dissociate it. If it dissociated due to collision near the earth the +m component could cause a cosmic ray shower of enormous energy. The energy of some observed showers is puzzlingly high.

If a charged particle of negative mass were detected in, say, a cloud chamber and mistakenly interpreted as a particle of opposite charge and positive mass, there would be seeming discrepancies in such things as the energy and charge balances of reactions that might occur. It would be interesting to see if corroborative evidence for the existence of particles of negative mass could be found by the cosmic ray experimenters, for such a discovery would have momentous importance.

References

1. Proceedings of the International Symposium on Gravitational Collapse, Dallas (to appear).

2. For an account of the work of Bondi, Brill, Weber, and Wheeler, on this point see D. R. Brill, Annals of Physics 7 (1959) p. 466. See also H. Bondi et al, Proc. Roy. Soc. 269A (1962) p. 21.