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Cosmic Gravitational and Electrical Stress, Model Calculation

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Abstract: We define the charge disparity in the universe to be the difference in positive and negative charge densities divided by the positive charge density. We then show that a disparity on the order of 10^{-17} would produce a repulsive electrostatic stress sufficient to overcome the attractive gravitational stress in the universe. We argue that a nonzero charge disparity is plausible, if not probable. We conclude that the dark energy invoked to account for the increasing rate of expansion of the universe may in fact be electrostatic energy.

Key words: cosmos, electrical and gravitational stresses

COSMIC GRAVITATIONAL AND ELECTRICAL STRESS MODEL CALCULATION

The attractive gravitational force between masses tends to decrease the rate of expansion of the universe, yet that rate is actually increasing. However, if the universe contains a net electrical charge, the electrostatic repulsion of the charged particles would tend to cause the rate of expansion to increase. The electrostatic forces could dominate the gravitational forces and lead to the observed increasing expansion rate. In what follows we argue that such a charge is plausible and present a heuristic model calculation to elucidate the effect.

During the initial rapid expansion of the universe the plasma it contains cools and at some stage the number of baryons present is “frozen in”. Charge conjugation invariance would dictate that baryons and their charge conjugate antibaryons should be present in equal numbers.

At a still later stage in the evolution lower mass leptons will be frozen in, and equal numbers of electrons and positrons should be present. This picture leads to the conclusion that matter and antimatter should be present in equal quantities. The best evidence available at this time indicates that the universe consists almost entirely of matter and no appreciable amount of antimatter. One must conclude that for some unknown reason antibaryons either were not produced or disappeared by an unknown process. By the same token positrons must also be absent, leaving a universe consisting of baryons and electrons. Almost all of the charge particles at this stage will be protons and electrons. The electrons were frozen in at a later stage than the protons and were produced in an entirely different set of reactions. Thus there appears to be no compelling reason to assume that protons and electrons are present in equal numbers, which is to say that there is no reason to suppose that the universe is electrically neutral. As noted above, the existence of a net charge could account for the observed increase in the rate of expansion. Any effect will be proportional to the square of the net charge. So either an excess or a dearth of electrons relative to the protons will produce the same result. As shown below only a very small fractional discrepancy between positive and negative charge distributions will produce an electric force sufficient to overcome the attractive gravitational force.

The following model illustrates our main point. Consider a spherical shell of radius R comprising uniform distributions of protons and electrons with number densities n_p and n_e (area^{-1}). The mass of the electrons can be neglected with sufficient accuracy for the present calculation. Hence the total mass of the shell is

$$M = 4\pi R^2 m n_p$$

where m is the proton mass. The total charge Q on the shell is

$$Q = 4\pi R^2 e n_q$$

where e is the electronic charge and $n_q = |n_p - n_e|$. So the net charge density is en_q.

Introduce a set of spherical polar coordinates and consider the gravitational force on a polar cap whose lower boundary is a circle at co-latitude θ. The force on an element of area dA is directed radially inward and is

$$dF_g = GMmn_p dA/R^2$$

The total force on the polar cap is in the negative z direction and is

$$F_g = 8\pi^2 G R^2 m^2 n_p^2 \int_o^\theta \sin\theta' \cos\theta' d\theta', \text{ so}$$

$$F_g = 4\pi^2 G R^2 m^2 n_p^2 \sin^2\theta$$

where $G = 6.67 \times 10^{-11}$ newton meter^2/Kg^2 is the gravitational constant.

F_g can be viewed as resulting from a surface tension T_g acting across the boundary at θ.

So

$$2\pi R \sin^2\theta T_g = 4\pi^2 G R^2 m^2 n_p^2 \sin^2\theta$$

Hence

$$T_g = 2\pi G R m^2 n_p^2.$$

Since both gravitational and electrical are inverse-square forces the electrical surface stress can be found from T_g by replacing $Gm^2n_p^2$ by $e^2n_q^2/4\pi\varepsilon_o$ and thus

$$T_q = Re^2n_q^2/2\varepsilon_o$$

T_q is an electrical stress similar to the surface tension T_g, but tending to cause expansion rather than contraction of the shell. The ratio of the surface stresses is

$$T_q/T_g = (4\pi\varepsilon_o G)^{-1}(e/m)^2(n_q/n_p)^2.$$

The stresses will balance when this ratio is unity or when

$$(n_q/n_p)_o = (4\pi\varepsilon_o G)^{1/2}(m/e)$$

a result that might have been expected at the outset. Substitution of the SI values for the parameters in this equation yields

$$(n_q/n_p)_o = 8.93 \times 10^{-19} \cong 10^{-18}$$

So only a very small disparity between the positive and negative charge distributions is required for the electrical repulsion to overcome the gravitational attraction and lead to a net stress tending to cause the sphere to expand or to increase its rate of expansion. This result follows from the fact that the repulsive electrical forces are so much greater than the gravitational.

In this model the particles are fixed in a two-dimensional space, the shell. The electrical force causes the shell to expand or increase its rate of expansion. An observer fixed on the shell senses its expansion by observing the increasing separation between particles. If the space itself is viewed as an elastic medium, the work done by the electric field goes into a combination of stretching the space and increasing the kinetic energy of the particles.

In the cosmic analog of the above model the electrical forces cause an increase in the rate of expansion of the four-dimensional spacetime surface that is the universe. A proper analysis of this system would require a model of the spacetime surface and a way to include the electromagnetic field in Einstein's field equations. Such an analysis would yield expressions for gravitational and electrical stresses distributed throughout space. These stresses must have the dimension of energy/volume. The gravitational stress, denoted by S_g, must be proportional to G and to the square of the density, mn_p. These conditions lead to the result

$$S_g = DGm^2n_p^2$$

Where n_p now denotes the number density of protons with the dimension of length^{-3} and D is a geometry-dependent coefficient with dimensions length^2. The corresponding electrical stress, S_q, is $S_q = D(e^2/4\pi\varepsilon_o)n_q^2$. It is interesting to compare these expressions for the volume stresses to the expressions found above for the corresponding surface stresses T_g and T_q.

By equating the expressions for S_g and S_q and then solving this equation for (n_q/n_p) we find

$$(n_q/n_p)_o = (4\pi\varepsilon_o G)^{1/2}(m/e) \cong 10^{-18}$$

This is the same numerical result as found in the shell calculation. Again we conclude that a charge disparity greater than about 10^{-18} would lead to an increase in the rate of expansion of the universe.

The preceding discussion neglects the effects of neutrons, dark matter and the entire zoo of unstable particles. This leads to an underestimate of gravitational forces but probably by no more than a factor of ten, so the critical disparity might be only 10^{-17}.

We know of no compelling reason to assume that positive and negative charges in the universe are exactly equal in number. Indeed in a universe devoid of antimatter created in distinct processes of baryogenesis and leptogenesis it seems the most probable outcome would be a nonzero net charge. Therefore it appears plausible that the increasing rate of expansion of the universe is caused by electrical forces and that the so-called dark energy is electrostatic energy.

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