Graviton scattering and matter distribution

(dark matter/background radiation/large-scale matter distribution/galaxy formation)

ROY J. BRITTEN

California Institute of Technology, 101 Dahlia Avenue, Corona del Mar, CA 92625

ABSTRACT In this model gravitation results from the emission and absorption of quanta (gravitons) that are scattered a few times in crossing a typical galaxy. Many features of the universe can be explained in terms of this model, although theoretical justification for the scattering of gravitons is lacking. Gravitons follow a random walk and diffuse through the outer regions of a galaxy. As a result the force of attraction follows a $1/R$ law, matching observed galactic rotation curves and explaining galactic dynamics without the need of dark matter. The model makes predictions regarding early stages in the expansion of the universe and the establishment of the mass distribution. It may be assumed that a nearly uniform expanding cloud of gas was present that was subject to collapse under gravitational forces. The $1/R$ law of attraction due to graviton diffusion is orders of magnitude more effective for initiation of collapse than the inverse square law, and it applies to blocks of gas larger than the graviton mean free path. Delay in the spread of gravitational attraction by diffusion sets a time-dependent range beyond which the attractive force is zero. In the model this causes arrays of matter to collapse locally into zones with a spacing set by the length of the range of the attractive force. An initial examination indicates that under these conditions the background radiation could have been released from a nearly uniform distribution at the time of decoupling of radiation and matter, followed by gravitational collapse into blocks of galactic mass. In the model the diffusion of gravitons continued and collapse became possible on a larger scale, initiating the formation of galactic clusters and still larger structures. The slow rate of diffusion then prevented the largest structures from attracting each other and permitted the formation of the voids on a very large scale. The model predicts that on the largest scale there is a three-dimensional repeated array of structures separated by voids. Ultimately structures larger than galactic clusters outran the diffusion of the gravitons and have since been freely expanding.

Major issues in cosmology include the formation of galaxies, the large-scale distribution of matter, the uniformity of the microwave background radiation, and the apparent dark matter. The issue of dark matter arises from two sets of observations. First, the velocity of rotation of the peripheral material in galaxies is typically nearly independent of radius as far out as can be measured. The current explanation is that dark matter is present in just the correct radial distribution and adds up to 5 or 10 times the visible matter of the galaxy (see, e.g., ref. 1). Second, the apparent gravitational attraction between galaxies and clusters of galaxies suggests the presence of much more invisible matter (ref. 2, summarized in table 12.1 on p. 329). This enormous excess of matter compared to what is visible has not been directly observed, and its presence is indicated only by the apparent gravitational forces. Recently the distribution of matter has been mapped in three dimensions by making use of the red shift of

individual galaxies and infrared satellite observations (3–5). On the largest scale examined there are immense voids and the galaxies are clustered in relatively dense regions. In the face of this heterogeneity the 3 K background radiation is apparently isotropic and uniform.

The proposal preliminarily examined in this paper is that gravitons are continually emitted by all matter at a rate proportional to the inertial mass and that their absorption by other matter (also proportional to the inertial mass) accounts for gravitational attraction. In this model the absorption of a graviton results in a slight transfer of momentum to the absorbing mass in a direction toward the mass that emitted the graviton. This is a specific characteristic of gravitons, since the absorption of other sorts of particles transmits momentum in the direction of travel of the absorbed particle. The emission of gravitons is supposed to be uniform in all directions and thus there is no measurable net momentum transfer to the emitting mass as a result of emission. In the model the inverse square law of attraction between two masses (which are not too distant from each other) is due to the uniform spreading out of gravitons in the intervening space. The magnitude of the individual momentum transfer is left open, though it is apparent that it must be very small and that the number of gravitons emitted is very large. It is proposed that gravitons travel at or near the velocity of light and have little if any rest mass.

The gravitational attraction is increased in certain regions by the retardation of outward flow of gravitons due to scattering. There is a resulting increase in the number of gravitons per unit volume in peripheral regions of galaxies and this takes the place of the dark matter. Scattering causes a deviation from the inverse square law. However, on the size scale of the solar system the inverse square law is quite accurately followed. Therefore it is assumed that large changes in direction of graviton travel occur only a few times in crossing a galaxy, though they may be the sum of many small changes. The movement of the gravitons and the clouds that form around any large concentration of matter are in analogy to the diffusion of gases. A test body, for example a star, absorbs gravitons from the cloud and the result is a gravitational force. The total force is obtained by estimating the concentration of gravitons at the star emitted by each mass in the galaxy and calculating the vector sum of the forces. In this way the attraction of matter towards a galaxy and the galactic rotation curves can be quantitatively explained.

Calculation of Galactic Rotation Curve. In the model, gravitons coming from all of the matter of a galaxy follow a random walk and diffuse outward to form a peripheral cloud. As a first step a point mass "galaxy" is assumed to be in a region where there is a constant probability of scattering. The solution of the diffusion equation for a point source is a useful approximation. Zero concentration at great distance is an appropriate boundary condition due to the slow diffusion process and the limited time since the beginning of the expansion. Thus:

$$W = bM/R \qquad [1]$$

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and

$$A = hM/R, \qquad [2]$$

where W is the number of gravitons per unit volume, M is the galactic mass, b and h are constants, R is the radius, and A is the acceleration inward due to gravitational attraction. Then the velocity (V) of a star in stable circular orbit around the galaxy is constant, independent of the radius:

$$V^2 = AR = hM. \qquad [3]$$

Observed rotation curves for many galaxies show a smooth rise in orbital velocity from the center which flattens at about the visual radius. Beyond this distance the velocity is constant out to about four times the visual radius, where measurement becomes impractical (1). Since Eq. 3 shows no change with radius it fits the observed galactic rotation curves in the outer regions. This equation shows in a particularly simple way that it may be possible to explain the apparent dark matter as due to the effect of a diffusing cloud of gravitons.

Eq. 3 fails inside the visual radius of a galaxy because it describes matter concentrated in a point. To examine distributed matter the direction between the test mass and the emitting matter was taken into account by vector addition of the forces of attraction. Each point on a spherical shell of matter was assumed to create a $1/R$ distribution of gravitons as in Eq. 1 and attract as in Eq. 2 with a force aimed at the point. The forces on a test mass were integrated over the whole shell and the result is given in Fig. 1. The circumferential velocity rises smoothly from zero at the center, achieves its steepest slope at the radius of the shell, and promptly flattens to a constant value. This is a close approximation to the force implied by the rotation curve of a galaxy. Integration over a distribution of shells and rings of stars would make it possible to calculate a galactic rotation curve matching observations in detail.

Origin of the Scattering. The major causes of scattering of gravitons to be considered are interaction with matter, electromagnetic radiation, other gravitons, or the vacuum. The direct interaction with matter can almost certainly be eliminated as the source of scattering by comparing the amount of
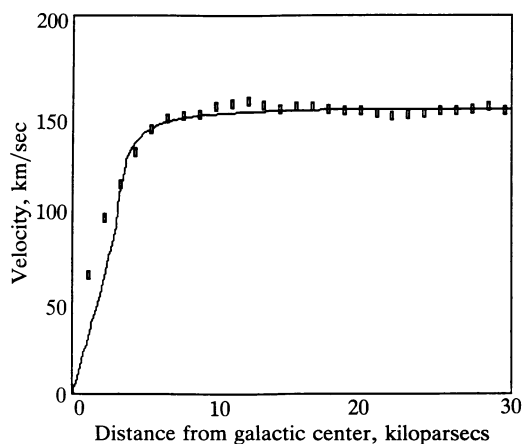

FIG. 1. Circumferential velocity for model calculation superimposed on measurements for NGC 3198. The solid line shows the velocity calculated for a spherical shell of matter on the basis of diffusion of gravitons, integrating the vector force of attraction for each point on the shell. The points are the measurements of rotation velocity for the galaxy NGC 3198 and the scales refer to these measurements. The calculation was for arbitrary scales and simply superimposed on the measurements. By choosing a distribution of shells of appropriate masses and radii a close fit to the data would be possible. (One kiloparsec = 3.09×10^{16} km.)

matter in a path through the galaxy with that in a path through the earth. Passage through stars is rare and can be ignored. The gas present in the galaxy is equivalent to about 10^5 H atoms per cubic meter, and the product of density times distance in the passage from the center to the periphery is roughly 10^5 kg/km^2. On the other hand, passage through the earth along a diameter amounts to 6×10^{16} kg/km^2. A limit on graviton interaction passing through the earth can be calculated from measurements of earth tides with modern gravimeters (see, e.g., ref. 6). The scattering of gravitons would affect the solar tide much more than the lunar tide, since the tidal difference is 0.017% of the solar gravitational force while it is 6% of the lunar gravitational force. Since the ratio of the tidal forces is predicted accurately from solar and lunar orbits, the limit for the reduction of the gravitational field on passing through the earth is very much less than 0.017%, possibly a part per million or smaller. As just calculated, the effect of passage through the galaxy would be smaller by a factor of perhaps 10^{11}, and thus direct scattering by matter need not be considered. The scattering by electromagnetic radiation seems unlikely in the galaxy at present. Further, both the amount of radiation and the gravitational field fall with increasing distance from the center of the galaxy, and if these were the primary source of scattering the calculations above would be seriously affected, leading to a deviation from observed galactic rotation curves. The simplest explanation of the constant extent of scattering assumed for the calculations above is an underlying interaction of the gravitons with the vacuum. However, interaction with other gravitons and possibly electromagnetic fields could contribute to scattering under extreme conditions, and this is left open in the model. If scattering by the vacuum is dominant, then it would occur in the regions between galaxies. Gravitons would diffuse in these regions, and gravitational attraction between nearby galaxies would diminish more slowly than the inverse square of the distance. The result would be an increased apparent gravitational attraction between galaxies. However, analysis of galactic clustering in this model requires examination of the time dependence of gravitation, resulting from the slow process of diffusion. The early period in the expansion is critical, when the seeds were probably formed for structures such as clusters and superclusters. There follows a preliminary discussion of this problem.

Time Dependence of Gravitational Attraction. In the model it is assumed that gravitons began to be emitted as the expansion of the universe started, and thus to discuss the early stages of expansion and the formation of galaxies and other structures an equation describing the early diffusion of gravitons is required. A relationship has been derived from Monte Carlo calculations assuming that individual gravitons traveled with a constant speed and a constant probability of scattering. A random number generator determined when scattering occurred and selected a new random direction of travel at each event. The radial positions as a function of time were summed for hundreds of thousands of individual gravitons. The following equation is a useful approximation for the quantity of gravitons in each spherical shell at a distance R from the point of release:

$$\text{Gravitons per shell} = (1 + AR/L)\exp(-BR^2/Lct). \qquad [4]$$

Here A and B are constants, c is the graviton speed, t is the time, and L is the mean free path. Least-squares fit out to about 50 times the mean free path gives $A = 1.733$, $B = 1.116$, and an average deviation that is less than 3% except at times so short that the gravitons have not yet been scattered.

Eq. 4 rises linearly with distance, reaches a maximum, and decays rapidly to zero. To obtain the force of acceleration Eq. 4 is multiplied by the galactic and test particle masses and the gravitational constant and divided by R^2 for the area of

the shells. In the region of linear rise of Eq. 4 the force follows a $1/R$ law. At the present epoch a maximum mean free path L of several kiloparsecs is required to explain the rotation curve of a galaxy such as that shown in Fig. 1. With this mean free path gravitons could travel by random walk a few megaparsecs in 10 billion years. If the mean free path were as short as a few parsecs, gravitons would diffuse only a 100 kiloparsecs (to the outer limits of a galaxy) in 10 billion years. It seems that the best initial estimate of the mean free path lies between these values.

Collapse Initiation and Uniformity of the Primordial Radiation. The assumption is made that gravitational collapse did not occur significantly before matter and radiation became decoupled, when the matter distribution was nearly uniform as implied by the uniformity of the background radiation (7). This is probably a workable assumption, since in the model the initiation of collapse has novel properties due to graviton diffusion and the resulting $1/R$ law of attraction. Small displacements of matter from a uniform distribution grow much more rapidly under the $1/R$ law that results from graviton scattering compared to the inverse square law because there is an enormously larger force increasing the displacement. To show this a computer calculation was made for a distribution of 125,000 uniformly spaced particles in a cube. In this calculation increasing displacement of the center particle gives a linear rise in force for the $1/R$ law and an approximately cubic rise from a very small force for the $1/R^2$ law. At a displacement of 0.1% of the particle spacing there was a 10 million-fold greater outward force for $1/R$ compared with a $1/R^2$ force law. This additional force would be effective on regional fluctuations in density rather than single atoms, since the $1/R$ law does not come into effect at distances shorter than the mean free path.

Gravitational "Range" and Matter Distribution. To estimate the predictions of the model it is assumed that gravitons begin to be emitted very early in the expansion. Scattering of the gravitons is assumed to occur, resulting in diffusion of the gravitons and establishing a $1/R$ law of attraction out to an appropriate distance from each atom. However, the distance traveled in random walk diffusion increases about as the square root of time, and thus gravitons reach short distances very rapidly (at the speed of light) but reach great distances very slowly. At any particular time the force of attraction towards a mass fades to zero at a distance shown in Eq. 4. The approximately exponential decay sets the range of the gravitational force.

Effect of Range in Simple Collapse Models. A first step in understanding the implications of a gravitational range has been to run simple computer models of collapse, and they exhibit a phenomenon of clustering that is termed zone formation. One calculation made use of an initial three-dimensional uniform array of large blocks of primordial gas (spaced 1 unit apart) that are attracted to each other with a $1/R$ law. The block dimensions are about equal to their initial spacing, and blocks may interpenetrate, so the force between each pair is calculated as $1/(R + 1)$. In each iteration the forces are summed and then the blocks are moved in proportion to the vector sum of the forces, assuming that the momentum gained in falling toward each other is all lost in the interaction of the atoms of gas. Variation in initial density is introduced by randomly displacing the blocks by a fraction of their spacing. If a force range is not introduced the array of blocks begins to collapse at the boundaries and ultimately the whole array falls in to the center. However, if the attractive force falls to zero at the range distance the result is entirely different. As the calculation proceeds, blocks collect in local zones. (The word *zone* is used to avoid confusion with *cluster*, *supercluster*, or *cloud*.) Soon each zone is outside the force range of all the other zones. Then the blocks that happen to be in each zone collect and the stable solution for

this simple model is a somewhat irregular array of zones made up of different numbers of superimposed blocks. The minimum spacing of the zones is determined by the range of the attractive force. The variation in the pattern is set by the initial variation in density (that was initially on a size scale very much smaller than the zone spacing). A convenience for small computers is that the limited range of the gravitational field eliminates the effect of boundaries of the matter array, except near the periphery. In a small calculation the internal regions go to the same solution that they would if they were part of a very large model calculation. This phenomenon has also been modeled by accelerating each block relative to the others (without viscous interaction), using Eq. 4 divided by R^2 for the force. In this version initial outward velocities are given to the blocks corresponding to the expansion of the universe. The results are similar to those of the previous calculation, including the formation of voids and zones.

The average number of blocks collected in the zones and their spacing are determined by the length of the range of the attractive force, and any reasonable variations of the initial array lead to the same average result for these parameters. The breakup into zones appears to be robust. The phenomenon itself apparently depend only on the existence of a range beyond which the attractive force is zero and not on other aspects of the model calculation. Logically the number and spacing of the zones depend somewhat on the force law, but it is unlikely that force laws (with a defined range) could be found that suppress the occurrence of zones. The important conclusion is that the spacing of the zones depends primarily on the range of the force. This result has strong implications for the distribution of matter in the universe if the principle derived from these simple calculations applies to early times in the expansion. The large-scale zones can be taken to contain the amount of mass included in the largest regions that have been observed to be separated by voids. Observations of these structures could ultimately be used to define the effective range of the gravitational force at a late critical period in the expansion. The demonstration that the formation of zones is determined by the range of the attractive force under conditions assumed to occur in an expanding cloud of hot gas awaits full-scale calculations, but for heuristic purposes it will be assumed that there is a time-dependent range of the gravitational force and that it determines the size of the zones on a variety of size scales.

Galactic Seed Formation. If the model is appropriate the early stages of graviton diffusion and collapse initiation should produce zones containing masses matching the mass distribution of galaxies. The initial approach here is to estimate how the initial breakup of a nearly uniform gas might occur. The mean free path for scattering might be reduced by the high density of radiation and gravitons at an early stage. In any case, other requirements set only broad limits for the mean free path at present. Thus a value for the mean free path can be chosen to be effective in the initial stages in galaxy formation. The assumption is that the amount of matter within a volume equal to the cube of mean free path for scattering was a significant fraction of the mass of a typical galaxy, even though the volume was initially small. At this early stage gravitons would travel several mean free paths fairly rapidly and then the net outward travel would slow down as diffusion began. Concomitantly, the law of attraction changes to $1/R$ from inverse square as shown by Eq. 4. The change to the $1/R$ law would initiate collapse and the retardation of outward graviton flow would allow time for the initial stages of collapse to become effective. Thus the gravitational range would start zone formation on the scale several times larger than the mean free path. Therefore it seems possible that in this model early parts of the collapse would have occurred preferentially on this scale, separating out regions of the mass of galaxies.

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Larger Scale Structures. Larger regions could separate at later stages of the collapse, finally forming the seeds of the largest observed voids and zones. The problem to be analyzed can be described in the following way. Several dynamic processes ran concurrently during the collapse: the expansion (a steady flow), the diffusion of gravitons (approximately as the square root of time), and the collapse on each of several scales at different times and matter densities. Each scale can be thought of as evolving towards dense regions separated by relatively empty regions as follows: protogalaxies and protointergalactic space, protoclusters, on up to protozones and protovoids on the largest known scale. The calculation required is not elementary, and parameters such as the gas temperature and distribution of the initial fluctuation in density and velocity will probably be important as well as the effective graviton scattering. The problem to be analyzed differs from previous calculations due to the diffusion of gravitons spreading with the square root of time and the effective range of the gravitational force.

Graphical observation of the collapse of model arrays where the gravitational force has a maximum range shows an initial stage of formation of empty seams between the regions that will later each fully collapse. There is no apparent difficulty for this to occur on one size scale and then later on a larger size scale after the range of the force has increased. The zones on the larger scale are each expected to be made up of many small-scale voids and zones that are well along in their collapse. Thus it seems intuitively likely that in the initial stages of the expansion of the universe the increasing retardation of the graviton diffusion caused collapse to be initiated on one size scale and then on a larger scale after a much longer time when the clouds of gravitons had diffused further outward. This could occur on several increasing size scales, seeding structures that would become galaxies, clusters, and superclusters. The largest scale may have occurred when absorption of gravitons or the lack of time for further diffusion of the gravitons determined an effective maximum range, and this would have set up structures corresponding to the largest-scale voids and zones that have been observed. Completion of the collapse on each of the size scales to form the present structure of the observable universe probably occurred at much later times, long after the seeds were formed. It is worth reiterating that in this model the initial fluctuation in matter density does not determine the size of the zones and voids that result from collapse. Zone formation is caused by the range of the gravitational force. The uniformity of the very early matter distribution and thus the uniformity of the background radiation is principally independent of the pattern of matter distribution that ultimately results from gravitational collapse. The model predicts that the largest size zones will be indefinitely repeated in a three-dimensional array at the spacing determined by the maximum range of the gravitational force. This suggests that there should be regularity in the spacing of the largest observable structures in the universe, which may well be the case.

One of the questions about the distribution of matter is that on several scales the structures show the apparent effect of gravitational attraction that almost led to gravitational capture. Nevertheless the structures are now expanding as shown by redshift measurements. It seems statistically unlikely under the usual rules of gravitation that structures on each of several scales of size escaped from gravitational capture after their seeds were formed. The graviton scattering model contains a novel mechanism of escape from gravitational capture. If the relative velocities of a set of elements of a structure had not quite been turned around from expansion to contraction, then the matter would outrun the gravitational field, which in the model expands ever more slowly due to the effect of the random walk and diffusion. As a result galaxies may remain individually gravitationally bound but larger structures expand with the universe. As mentioned above, the time required for gravitons to diffuse large distances depends on the mean free path in intergalactic regions. If it is assumed that the scattering is due to an interaction with the vacuum, then the intergalactic mean free path would be about the same as that within galaxies or a few kiloparsecs. Then the range of the gravitational force would be limited to a few megaparsecs at the present time, after about 10 billion years of diffusion, and this would strongly reduce intergalactic gravitational attraction. There does not appear to be any evidence that actual gravitational attraction exists at these distances except that it is a convenient explanation of clustering. In this model the clustering on each scale results from conditions early in the expansion.

Observed clusters often include many galaxies per cubic megaparsec (8), and within these regions the gravitational forces at the present time are very likely significant in the model. Assuming that a constant mean free path (near the maximum value) extends to such distances, the force of attraction with the $1/R$ law in the model is much greater than traditionally expected gravitational forces resulting from a $1/R^2$ law. Such clusters may be gravitationally captured and not expanding. However, distances between clusters are typically a few megaparsecs even in rich regions (8), and in the model they are gravitationally out of touch—that is, separated by distances such that graviton diffusion does not catch up with their relative velocities. The observed distances between them indeed appear to be expanding, based on their relative redshifts.

Graviton Mechanism. The primary unexplained assumption in this model is that after emission from one mass a graviton may be scattered multiple times and nevertheless when it is absorbed by a second mass the momentum transfer is in the correct direction to cause an attractive force on the absorbing mass towards the emitting mass. The underlying mechanism is not easy to visualize, but the problem arises for any model that includes gravitons. The following suggestion is quite speculative. The graviton could include in its structure an analog to quantized spin that would account for the peculiarities of the momentum transfer. In analogy to ordinary spin there might be just two directions possible in a ground state and in that way it could retain the direction in which it was emitted through many scattering events. Upon absorption this spin aspect is proposed to give a pulse of momentum back along its axis of orientation. While this proposal is incomplete, the spin analog mechanism might have observable characteristics. There is no doubt that if gravitational quanta exist their peculiar momentum transfer properties are not like those of ordinary matter or quanta. Nevertheless, the proposal that gravitons could pass through matter undiminished while transferring momentum is not considered, since it appears to break conservation rules.

Discussion. It is worth noting that the rotation curves of galaxies are not always precisely consistent with a $1/R$ law of gravitational attraction. The cases where the rotation velocity falls slowly with increasing radius could be explained in the model by an increasing mean free path deriving from a reduction in scattering from other gravitons. In the cases where the velocity rises slowly with radius a careful search for ordinary peripheral matter should be made, considering that graviton diffusion would be responsible for most of the phenomenon.

Even if some aspects of this model do not survive, the principle of breakup into zones seems robust and requires only that gravitational attraction have a limited effective range at an appropriate time. The very possibility of alternative models of this sort reduces the certainty and generality of cosmological arguments. For example, it weakens the potential contradiction between the uniformity of the back-

ground radiation and large-scale matter distribution. The scattering of gravitons is not apparently implied by the general theory of relativity, but no quantum version has yet been successful.

The elimination of the need for dark matter in this model suggests that estimates of the amount of matter should be based on the observable matter in the universe. Thus in the model the possibility of ultimate recollapse of the universe needs careful reconsideration, and it is not easy to say what would happen at very late times with enormous voids separating regions with large amounts of matter. There is no way at this moment to examine such ramifications, and that is not a purpose of this paper. The essential points are (*i*) that graviton scattering could explain the apparent dark matter as the result of the deviation from the inverse square law; (*ii*) by making early collapse of local regions from a nearly uniform gas more likely it reduces the conflict between large-scale structure and the uniformity of the primordial radiation; (*iii*) the model may explain the formation of galaxies; (*iv*) it is consistent with the presently observed expansion of large structures that initially must have been formed by gravita-

tional collapse; and (*v*) the model predicts that very large-scale structures should form a repetitive three-dimensional array.

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