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Nonuniform spatial expansion and galactic gravitational effects

J.H.Wierenga

Abstract

Observations that the orbital velocities of stars in the spiral arms of galaxies remain more or less constant with increasing distance from the galactic center are typically explained by postulating the existence of dark matter halos in which the galaxies are embedded. Modified gravity explanations are seen as the only viable alternative, for either gravity works as predicted by GR, in which case there must be some other source of gravity than the observed baryonic matter (i.e., dark matter halos), or gravity is not accurately described by GR. This paper takes a third view: gravity is as GR describes it, and there is no other source of gravity, but it is rather our understanding of distance which is at fault. Current theory does not consider the possibility that space expansion is nonuniform, resulting in a difference between trigonometrically observed and gravitationally effective distances. Supposing local expansion of space occurs, and the magnitude of this expansion diminishes with increasing distance from the galactic center, then the observed baryonic mass of the galaxy may be sufficient to produce the orbital velocities of stars in the spiral arms, as observed by means of redshift.

We show that this hypothesis can account for galactic rotation curves, galactic morphologies, gravitational lensing of both globular clusters and colliding galaxies, and the uniformity of the expansion of the universe, including the discrepancies between measurements of the Hubble expansion based on Cosmic Background Radiation and those based on pulsating stars in local galaxies. The hypothesis achieves this using only observed masses, motions and energies, together with inferred masses of black holes, plus gravity as it is conventionally understood to behave. Further, the hypothesis leads to the identification of a possible source of space expansion.

We conclude with a list of tests which may be applied in order to corroborate or falsify our hypothesis.

Keywords: scale factor – rotation curves – galactic morphology – space expansion – black holes

1 LOCAL VARIATION IN THE SCALE FACTOR

The assumption that the expansion of space is uniform is based on our observations that space has expanded uniformly for any given time period, regardless of which direction we look. However, nonuniform expansion is also quite compatible with these observations, provided that excessive local expansion dissipates into surrounding volumes during the course of time. The assumption of uniformity is not the only possible conclusion on the basis of observations, and cannot be used as an argument against locally variant expansion, any more than the level surface of a spring-fed lake can be used to argue that the entire lake bottom is necessarily a single, uniform spring.

In this paper we assume that space expands *into itself*, in other words that local expansion of space occurs in such a way as to result in more space, without directly affecting the surrounding space. For example, if space expands within a closed sphere, but not outside of it, distances, areas and volumes within the sphere will expand, whilst the surface area of the sphere will remain unchanged. The space within the sphere is *richer* than the surrounding space. We define space to be *rich* to the degree in which the distances within the volume, as measured by the passage of light, are larger than our trigonometric calculations of those distances. In other words, the scale factor — a — in rich space is higher than that of the observer. As conventionally understood, a is a numerical value, without units. Its value at any point in space-time is the limit, as line length tends to 0, of the ratio between the actual length of a line through that point and perpendicular to our line of sight, and the length we would assign to the line on the basis of trigonometric calculations. By this definition, $a = 1$ on Earth, now.

The assumption that space expands into itself is based on the expectation that, whenever a region of space expands due to a local cause, this initially produces only local effects. Otherwise we would have a physical process — the transmission of space expansion effects, including the reduction of the magnitude of gravitational potential energy at points distant from the cause — which acts at a speed greater than that of light. Thus, for some period at least, the surface area of the expanded region will stay the same, whereas the volume of the region may increase dramatically. This increase in volume cannot, however, be detected within the region. Everything looks normal. All the laws of physics remain applicable. Any experiment we perform in local space will have exactly the same results, regardless of how much local space has expanded, provided that its scale factor is constant.

We can, however, detect a difference between the scale factor in our neighborhood and points elsewhere, because the distances we calculate on the basis of trigonometrical arguments will differ from the effective distances, that is the distances which dictate the conformance to physical laws, such as the invariance of the speed of light. If the scale factor differs, this will be observable.

Redshifting of light occurs when the space through which light travels expands *while the light is traveling through it*, and, of course, as a result of the source of the light moving away from us. Note that we should not expect that light which reaches us from a source with a higher scale factor will therefore be blueshifted in proportion to the ratio of source to destination scale factor, because no mechanism presents itself to supply the required additional energy. In consequence, we cannot detect directly whether the source of light is located in richer space, provided that the richness and poorness of space en route is stable. On the face of it, differences in redshift from stars in the same galaxy are therefore a reliable indication of differing motions of those stars relative to us.

Note that our hypothesis requires that the space richness within a galaxy moves with it. This makes our hypothesis incompatible with any conception of space which declares it to be not anything at all.

In the following sections we shall first discuss how the scale factor needs to be related to the galactic radius in order to produce the rotation curves which are observed. We shall then explore a possible cause for the variation in scale factor. Finally, we shall sketch how the variation in the scale factor accounts for the phenomena which are typically adduced in support of dark matter halo theories.

2 RELATIONSHIPS BETWEEN SCALE FACTOR, MASS AND ORBITAL VELOCITY

2.1 A mass distribution model of spiral galaxies

In this section, we shall base our discussion on a simplified model of the mass distribution within a typical spiral galaxy. We understand it to consist of three zones, as follows:

1. the *bulge*, in which $M'(< r)$ is proportional to r^2
2. the *stellar disk*, an elliptical slab of stars lying in the plane of the galaxy and which, although containing concentrations of stars due to inner spiral arms and other features, nevertheless contains sufficient baryonic mass between these concentrations for $M'(< r)$ to be more or less proportional to r
3. the *outer spiral arms* — henceforth referred to as *arms* — extending from the stellar disk into surrounding space which is otherwise largely devoid of baryonic mass, and for which $M'(< r)$ is more or less constant.

Note that the baryonic mass contribution of the arms is typically negligible, compared with the bulge and stellar disk.

2.2 Gravitation in space with locally variable scale factor

The behavior of gravity in space in which the scale factor is variable — and hence distances are not what they seem — can best be understood by applying the Gaussian formulation of Newtonian gravity. The gravitational flux exerted by a mass on any closed surface containing that mass is, as Gauss observed, a constant depending only on the mass, regardless of distance. In the Gaussian formulation, the gravitational flux due to a massive object of mass M on any closed surface surrounding that object is a constant, given by the formula

$$\oint g.dv = -4\pi GM, \tag{1}$$

If we take an isodistant surface at distance r from a mass M, g is uniform, so we have

$$g = \frac{-4\pi GM}{4\pi a^2 r^2} = \frac{-GM}{a^2 r^2} \tag{2}$$

where a is the scale factor at the surface, relative to the observer. If the scale factor is 1, this formula reduces to the conventional theory. But if it is smaller than 1, $-g$ will be larger than conventional theory would predict. Therefore, if the scale factor in the spiral arms of a galaxy diminishes with increasing radius from the galactic center, it is possible that the orbital velocity remains more or less constant.

The orbital velocity v of a star around the galactic center is given by the formula

$$g = -\frac{v^2}{ar} \tag{3}$$

Combining formulae (2) and (3), we obtain

$$v = \sqrt{\frac{GM}{ar}} \tag{4}$$

2.3 Application to relating $a(r)$, $v(r)$ and $M'(< r)$

We can deduce how the scale factor in the arms varies with distance from the galactic center by applying the observation that orbital velocities remain more or less constant with increasing radius. If the velocity within the arms is more or less constant, so is its square, so we have

$$v^2 = k_a \tag{5}$$

for some constant k_a.
Therefore, ignoring for the moment the gravitational effects of mass within the arms on the stars within it, we have

$$\frac{G(M_b + M_d)}{ar} = k_a \tag{6}$$

where M_b and M_d are the masses of the bulge and the stellar disk respectively.
Therefore

$$a = \frac{G(M_b + M_d)}{k_a}\frac{1}{r} \tag{7}$$

In other words, the scale factor a in the spiral arms is more or less directly proportional to the inverse of the distance r from the galactic center, supposing that the matter in the arm itself has only a marginal effect on the gravitational forces experienced by a star within it.

Note that the above formula is equivalent to the conclusion that the effective surface area $S(r)$ in the spiral arms is more or less constant, for we have

$$S(r) = 4\pi(ra)^2 = 4\pi(\frac{G(M_b + M_d)}{k_a})^2 \tag{8}$$

which does not depend on r. Note that this conclusion applies wherever the scale factor is inversely proportional to the radius.

Let us assume that the relation of the scale factor to the radius is the same for the bulge and the stellar disk as it is for the arms. This assumption is warranted if the dissipation of richer space to poorer space is a phenomenon dictated entirely by space, and thus unaffected by mass. If this is the case, then the orbital velocity of stars within the stellar disk may be determined as follows.

The mass $M(< r)$ of the galaxy contained within a distance r from the center is approximately the sum of the mass of the bulge M_b and the density per unit area of the stellar disk b_d times the area of the disk within radius r of the galactic center, i.e.

$$M(< r) = M_b + \pi b_d(r^2 - r_b^2) \tag{9}$$

where r_b is the radius of the bulge. Only the mass closer to the center exerts any net gravitational attraction, so we have

$$v^2(r) = \frac{G(M(< r)}{a(r)} = k_a(\frac{M_b - \pi b_d {r_b}^2}{G(M_b + M_d))} + \frac{k_a}{G(M_b + M_d)}r^2 \tag{10}$$

For larger r this makes v approximately linear with r, which is consistent with observations.

It should be expected that the scale factor increases dramatically as r decreases. If the observations are interpreted without taking this into account, the effective distances will be dramatically underestimated, leading to both overestimation of the mass density on the basis of observed luminosity and underestimation of the mass in the galactic core. To determine the extent of such errors would go beyond the purpose of this paper, given the paucity of reliable measurements with which to confront our hypothesis.

3 CAUSES OF VARIATION IN THE SCALE FACTOR

3.1 Diffusion of space

The local variation in the scale factor can be explained as the result of diffusion of space, as follows. Let us assume that the center of the galaxy is a fountain of space, generating new space at a constant number of cubic meters per second, and that this new space diffuses into the surrounding volumes in proportion to the surface area over which the diffusion takes place. Note that it is not necessarily the case that all the additional space is passed on immediately. The outgoing flow for a particular surface may be limited by the speed at which the neighboring poorer space can absorb new space, and the incoming flow could in principle exceed that. In such a case, the space in the vicinity of the source becomes more rich. As long as the center of the galaxy is producing new space, a scale factor differential may be maintained. Whenever the production of new space ceases, the scale factor within the galaxy is expected to tend to uniformity.

If the rate at which poorer space can accept new space is the determining factor in the diffusion of space, it follows that an initial state in which the scale factor is more or less directly proportional to the inverse of the distance from the galactic center r will be perpetuated as long as the center of the galaxy produces enough new space. For then the speed of diffusion across the isodistant surface at radius r within the spiral arms is proportional to the effective area of that surface, which is constant.

3.2 Black holes as a source of space

On the face of it, the most plausible sources of local space production are black holes, given that the centers of galaxies are known to contain supermassive black holes. We find black holes at the scene of the crime, so to speak. Further, black holes are perhaps the only things of which our understanding is insufficiently complete to justify a priori rejection of the assertion that they produce space. Suppose, therefore, that black holes produce new space, sufficient to account for observed spatial expansion. If this is the case, then the term with the cosmological constant in the Einstein Field Equations is unnecessary, and we should replace it with a term which covers the pressure of spatial expansion. This spatial expansion, as we have argued, does not appear to depend on the density of matter, but only on the geometry of space.

Perhaps the best way to understand what this term is, is to express the EFE in terms of pressure. Let us use the final sigma — ς — to denote this pressure in the pressure version of the EFE. ς is clearly a tensor, analogous to the stress energy tensor. This gives us

$$\frac{c^4}{8\pi G}(R_{\mu\nu} - 1/2Rg_{\mu\nu)} = T_{\mu\nu} - \varsigma_{\mu\nu} \tag{11}$$

We place ς on the right hand side because it is a form of energy, capable of increasing the spatial separation between masses and thus reducing the magnitude of the gravitational potential energy. A change on the left hand does not have the same effect. It does not of itself change the gravitational potential energy between neighbouring point-masses.

Suppose now that there is some natural limit to the left hand side, in other words, that space-time can be curved only to a particular amount. However, the limit would have no effect on the stress-energy tensor, which will continue to increase as long as mass is added to the black hole. It follows that the space creation pressure $\varsigma_{\mu\nu}$ will increase to compensate for the added mass. Variations in the rate at which mass falls in to the black hole will result in corresponding variations in the space generation pressure, and hence lead to irregularities in galactic rotation curves. Note that such a limit would have the effect of preventing the mass within the black hole collapsing into a singularity. The avoidance of singularities is by itself sufficient reason to consider the possibility of such a limit existing, as it opens the way to an understanding of black holes which makes more physical sense.

4 REPRODUCIBILITY OF PHENOMENA

4.1 Orbital velocities

In this section we shall confine ourselves to the curves compiled by Sofue (2016), see Figure 1.

These galactic rotation curves share the following features:

1. For low radii, a more or less linear increase of the orbital velocity with increasing radius, *followed by*
2. a peak in the orbital velocity, typically at the edge of the stellar disk, *followed by*
3. a more or less constant orbital velocity for the arms.

As our hypothesis leads to the prediction that the leveling off of orbital velocities more or less coincides with the point that $M'(< r)$ goes from being proportional to r to being constant, systematic observations of the relationship between $M'(< r)$ and $v(r)$ are required in order to validate the hypothesis. However, we are not aware of such a study. This is perhaps due to this being irrelevant to validation of the prevailing dark halo hypothesis. Clearly, this is area that needs further investigation.

Our analysis of the orbital velocities in the arms depended on the assumption that the net contribution of matter within the spiral arm on the orbital velocities is marginal. We expect this to be indeed the case, based on the following arguments:

1. The linear nature of a spiral *arm* results in stars along the arm experiencing gravitational attraction due to matter in the arm in both directions along the arm. Accordingly, this matter will exert an outward gravitational force on stars close to the stellar disk, which may explain the dip on orbital velocity at the beginning of the arm, as is consistently observed.
2. The matter in the arm will exert no net gravitational attraction on stars halfway along the arm, and an inward pull on matter at the end of the arm. Together with the effect of decreasing space richness exactly canceling out the effect of increasing distance from the center, this results in a slight increase in orbital velocity as the radius increases. Discontinuities or attenuation of the mass per unit length of the spiral arm may turn this increase into a slight decrease.

This accounts for observations that the orbital velocity of stars in the arms stays more or less constant, including non-luminous extensions to the arms, and that for some galaxies the orbital velocity increases steadily.

There is a wide variation in the observed patterns of those parts of galactic rotation curves that pertain to the *stellar disk*. However, it is in all cases observed that orbital velocity increases monotonically with the distance from the galactic center. This is applicable to both those galaxies with and those without spiral arms.

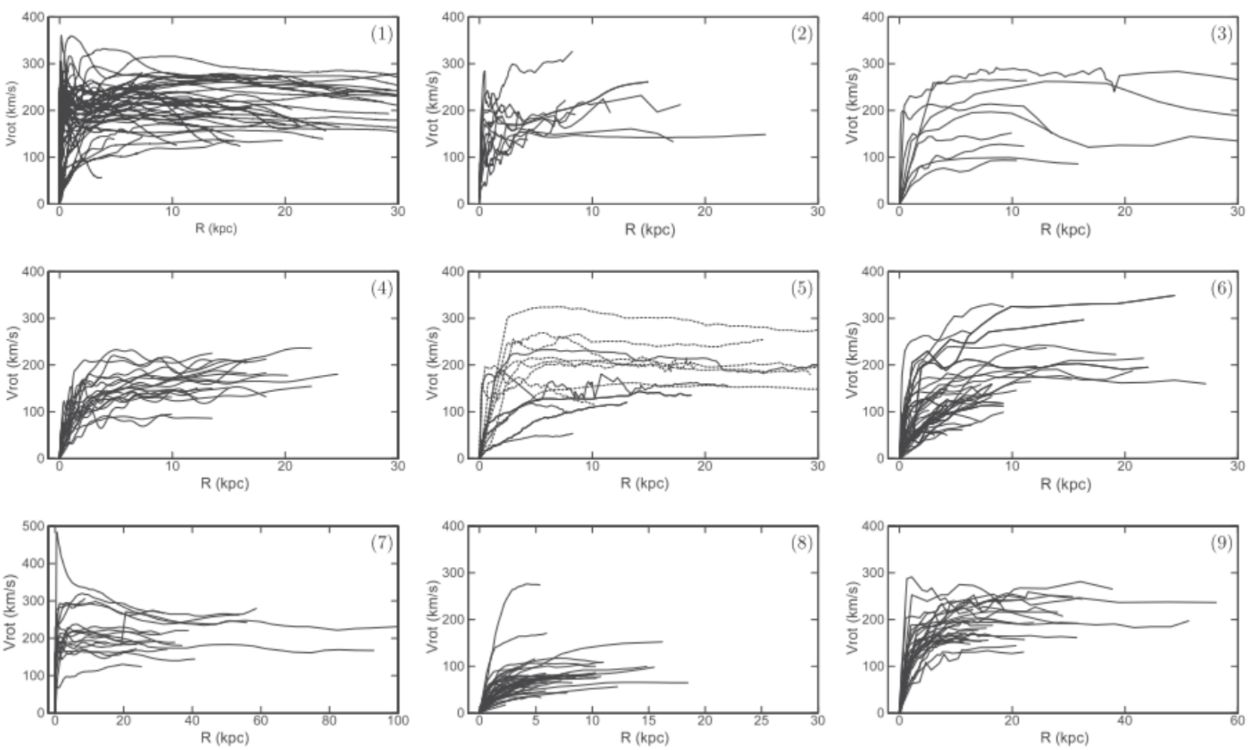

Figure 1. Figure 1: Sofue's compilation of galactic rotation curves: Rotation curves compiled and reproduced from the literature. References are in the order of panel numbers. (1) Sofue et al. (1999): nearby galaxy rotation curve atlas. (2) Sofue et al. (2003): Virgo galaxy CO line survey. (3) Sofue et al. (1999): NGC 253 revised; Ryder et al. (1998): NGC 157; Hlavacek-Larrondo et al. (2011a): NGC 253; Hlavacek-Larrondo et al. (2011b): NGC 300; Erroz-Ferrer et al. (2012): NGC 864; Gentile et al. (2015):NGC 3223; Olling (1996): NGC 4244; Whitmore, McElroy, and Schweizer (1987): NGC 4650A; and Gentile et al. (2007): NGC 6907. (4) Marquez et al. Ât(2002): isolated galaxy survey. (5) de Blok et al. (2008): THINGS survey, where dashed galaxies are included in (1) and were not used in the analysis.(6) Garrido et al. (2005): GHASP survey. (7) Noordermeer et al. (2007): early-type spiral survey. (8) Swaters et al. (2009): dwarf and low-surfacebrightness galaxy survey. (9) Martinsson et al. (2013): DiskMass survey

Our hypothesis is entirely consistent with these observations, as can be deduced from equation 10.

4.2 Morphology of spiral arm galaxies

If the scale factor within a galaxy is uniform, a radial arm (like a spoke) would quickly become curved as the galaxy rotates, even if all the stars were indeed revolving around the center with the same velocity. This is because the outer stars have further to travel to complete an orbit. The arm would, after a few galactic rotations, become increasingly curved and wind around the galaxy ever tighter. However, we do not observe such galaxies. This discrepancy between theory and observation is known as the *winding problem*. The winding problem would be even more acute if the outer stars had orbital velocities consistent with Newtonian or GR gravity, that is that they had lower velocities than inner stars. With our hypothesis the situation is different. As we have observed, the effective orbital velocity v within a spiral arm will remain more or less constant with increasing radius r, because the richness of space is inversely proportional to r. The angular velocity of a star at r is given by the orbital velocity divided by the effective length of the orbit, that is

$$\omega(r) = \frac{v}{2\pi ra} = \frac{v}{\frac{2\pi rGM}{k_a r}} = \frac{k_a v}{2\pi rGM} \tag{12}$$

which is constant. In other words, a spiral arm will not wind increasingly around the galactic center, because the angular velocity is the same for all radii. With our hypothesis, the winding problem evaporates. The observed morphology of spiral arms is entirely to be expected.

Does this mean that there is some mistake in the calculations which demonstrate that the rotational stability of spiral arms is due to a density wave which traps passing matter? Lin (1964). Not at all! The density wave adds to the stability of spiral arms, even though it may not be the cause of their existence.

When the a value of the scale factor reaches that of intergalactic space, it does not decline further. The inverse square law resumes operation, so that the galactic winding effect starts to operate, and outward moving matter loses its connection to the arms. Morphologically, it no longer belongs to the galaxy.

4.3 Spatial expansion

Local expansion of the universe will cause global expansion of the universe, because the new space of galaxies will diffuse to intergalactic space and increase its richness. Because light on its way to us from distant galaxies passes through the intergalactic space while it is expanding, it will redshift. We may expect that all the galaxies in the universe together produce the observed Hubble expansion. The value of a for intergalactic space determines our experience of Hubble expansion.

Recent measurements of the Hubble constant produce different values of the Hubble constant for large distances and short. Studies based on Cosmic Microwave Background Radiation result in a figure of 67.4 km/s/Mpc N. Aganim et al (Planck Collaboration) (2018), whereas those based on pulsating stars in local galaxies result in a figure of 73,4 km/s/Mpc Riess (2018). This is exactly what one would expect if our hypothesis is true. Space will be richer in the intergalactic space between neighboring galaxies than in space in general, because it will be fed by those galaxies. A greater supply of new space leads to more rapid expansion.

Note that this explanation for the expansion of the universe does not require dark energy. The explanation identifies the production of space by — presumably — black holes as dark energy.

4.4 Gravitational lensing

It is observed that gravitational lensing due to globular clusters is far more powerful than the observable baryonic matter of the globular clusters would lead us to expect. Detailed analysis of the contributions within the cluster to the lensing indicate that these contributions peak in the inter-galactic space Tyson et al. (1998). In conventional cosmology, that is explained by postulating that that is where the dark matter happens to be concentrated. In our hypothesis, intergalactic space has the poorest space, so that less mass is required in order to produce the same amount of lensing, as compared to the space within a galaxy. This also applies to the lensing around the cluster as a whole: the space around the cluster is so much poorer that the observed lensing is far in excess of that which we would expect. Our hypothesis makes it possible to avoid the conclusion that the globular cluster contains many times more mass than we infer from luminosity.

It is observed that when galaxies collide, the original galactic cores continue to determine the gravitational lensing effects, regardless of the existence and location of new concentrations of matter due to interactions between the galaxies Clowe et al. (2003). This is consistent with our hypothesis, presuming that the rate of space diffusion is slow. The collision does not last long enough for substantial diffusion of rich space into poor space.

5 CONCLUSIONS

Our hypothesis is amenable to testing, or rather to confrontation with existing and new observations. If the hypothesis is correct, we should observe the following:

1. Consistency in the effects usually attributed to dark matter, on the basis of logical relationships between

observable properties of galaxies, such as brightness, luminosity profiles, rotation curves, morphology and metallicity, with the fundamental properties that our hypothesis suggests.

2. Consistent values for the constants which determine the rate of space diffusion, as observed in galactic collisions, the morphology and lifetimes of galaxies, and the Hubble expansion.
3. Peaks in rotation curves at edges of stellar disks.

We have shown in admittedly sketchy terms that our hypothesis has the potential to account for the phenomena which are typically advanced as evidence for the existence of dark matter. That falls a long way short of being a convincing argument, but it does make the hypothesis worthy of further examination. We challenge the cosmological community to examine the hypothesis, applying its combined knowledge and skill to confront it quantitatively with existing and new observations and develop it further.

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