Central Configurations and Creation

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Abstract

Dark matter was originally introduced to explain galaxy rotation curves. Later, it was also invoked to explain the behavior of galactic clusters and to explain and model gravitational lensing. It is part and parcel of the currently accepted mainstream cosmological model of the evolution of cosmic structure in general, the "Lambda Cold Dark Matter" (ΛCDM) model. Creationists have been encouraged to accept dark matter because it offers evidence of design and stability in the universe, two characteristics that are expected from a Creator Who pronounced His cosmos as good, and even very good. In this paper, we present central configurations that offer a mathematically rigorous explanation of rotation curves without recourse to dark matter. We also look at a refutation of this explanation, an analysis of the refutation, and a possible application to creation cosmology.

Simple Summary

Dark matter is widely used in mainstream cosmology, specifically the ΛCDM model, to explain why the measured circular speeds (rotation curves) of spiral galaxies remain flat or rise at their outer edges instead of declining as expected. Creationists have sometimes accepted dark matter because it suggests design and stability in the cosmos. However, this article presents an alternative explanation using "central configurations," which are mathematically rigorous solutions to the Newtonian N-body problem that describe how groups of discrete bodies can maintain their shape while rotating. Donald Saari claimed that the standard formula (Equation 1) used by astronomers to estimate a galaxy's mass from its rotation speed is inappropriate for systems of discrete stars (N-body systems), leading to overestimated mass predictions, especially at the outer edges. This idea was challenged by Kadowaki, who argued that the failure of Equation (1) is due to its assumption of spherical symmetry, which galaxies lack, rather than the mass distribution being discrete. Kadowaki concluded that standard methods already account for non-spherical shapes and that the impact of discreteness is negligible, making skepticism about dark matter unwarranted. Despite this refutation, the sources suggest that Saari was justified in using Equation (1) because it often serves as a "standard approach" in galactic dynamics, particularly when considering objects at the outer edges of galaxies. The study of central configurations provides a framework that creationists can explore as a possible basis for astronomy and cosmology that focuses on design and stability without requiring dark matter.

Introduction

One of the lines of evidence for the existence of dark matter in the universe involves the rotation curves, or circular speed curves, of spiral galaxies. The acceleration of an object in circular motion with speed v_c and distance r from the center is the centripetal acceleration $a=v_c^2/r$. If the only force on the object is gravitational, this will be the gravitational acceleration, which is due to the distribution of mass near the object, usually expressed in terms of a mass density distribution. This distribution will define a gravitational potential whose gradient is the gravitational force. Hence, there arise various potential-density pairs that describe the mass distribution (density) in galaxies and potentials generated by them. Binney and Tremaine (1987) devote an entire chapter to Potential Theory in which they present the potentials for a number of continuous mass configurations. In particular, for a spherically symmetric density distribution, $\rho(r)$, they derive the expression for circular speed at distance r from the center

$$v_c^2 = \frac{GM(r)}{r}$$

where $M(r)$ is the enclosed mass at distance r from the center and G is the universal gravitational constant. This can be rewritten as

$$M(r) = \frac{r v_c^2(r)}{G} \tag{1}$$

The circular speed then provides a way to measure the mass interior to r for spherical systems.

In deriving Equation (1), Binney and Tremaine (1987) made use of Newton's first and second theorems (not to be confused with Newton's *laws*):

- Newton's First Theorem: A body inside a spherical shell of mass experiences no net gravitational force from the shell
- Newton's Second Theorem: A body outside a spherical shell of mass behaves as though the shell's mass is concentrated at the center

Binney and Tremaine (1987) also consider the potential (and in some cases the circular speed and/or the density distribution) for: a point mass (circular speed decreases with increasing radius as $r^{-1/2}$: Keplerian); a homogeneous sphere (circular speed increases linearly with radius: a rigid body); a power-law density profile (mimicking the luminosity profiles in many galaxies); a number of flattened systems (disks); ellipsoidal systems; axisymmetric systems; triaxial systems; axisymmetric disks; and non-axisymmetric disks. Linear combinations of these potentials are also available as models of mass density distributions of galaxies. In other words, astrophysicists have the tools to model a wide variety of mass distributions.

Of particular interest to the present discussion is the representation of disks as flattened spheroids. (Section 2.6.1 of Binney and Tremaine, 1987) Here they say: "disks differ from spherical distributions of mass, for which the force at r_0 depends only on the density at $r < r_0$. In fact, the surface density of a disk at $R > r_0$ affects the attraction at r_0 because the annulus of material exterior to r_0 actually pulls a star placed at radius r_0 outward…At points in a disk where little matter is pulling outward, for example, on the perimeter of a sharp-edged disk, the circular speed can be much higher than at the edge of the spherical body with the same total mass and radius." (Binney and Tremaine, 1987, p. 72)

Spiral Galaxies

Since we are mainly concerned with spiral galaxies, a few words about them are in order. The observable components of a spiral galaxy include (Wikipedia, 2025):

- A central bulge of stars, which resembles an elliptical galaxy
- A flat, rotating disc of stars and interstellar matter (gas and dust), including the spiral arms
- A near-spherical stellar halo, including globular clusters

There is also a tenuous outer disc of gas, which Nelson (1988) calls the disc corona.

The central bulge, or spheroid, is referred to as a Population II system and is relatively small compared to the disk, at least for our Milky Way Galaxy. A Population II system contains stars with little or no net rotation, large random velocities, low heavy element abundances, and no young stars. The disk is made of what are known as Population I stars, along with gas and dust. The spiral arms are populated by bright O and B stars, gas, and dust. O and B stars are said to be young stars. Population I stars contain more heavy elements than Population II stars, since, according to theories of stellar evolution, they formed from the remnants of older stars. The disk, including the spiral arms, does exhibit rotation.

The surface brightness of spiral galaxies obeys an exponential law, and if the surface mass density is also modeled by an exponential law (see the section on mass-to-light ratio below), the rotation curve of spiral galaxies should be divisible into three regions:

- an inner region with circular speed rising linearly with distance from the center;
- a "turnover" region where the circular speed is maximum and then declines; and
- a region where the circular speed falls off in a Keplerian fashion as one over the square root of the distance: $r^{-1/2}$ (like planetary motion in the Solar System).

Most measured rotation curves display the first two regions, but the Keplerian region is not observed. Instead, most rotation curves are nearly flat or slowly rising with increasing distance from the core past the turnover region. As an example, the rotation curve for the galaxy M33 is shown in Figure 1. For M33, the speed increases linearly beyond the turnover region. The currently accepted explanation for these higher-than-expected circular speeds is that there is unobservable matter (dark matter) present, distributed in halos that extend past the optically observable portion of the galactic disk. The inferred *dark matter* halo should not be confused with the observed *stellar* halo mentioned above.

Dark Matter and Creation Science

Dark matter has been incorporated into the prevailing cosmology known as ΛCDM (Lambda Cold Dark Matter). Faulkner (2023) provides a history of dark matter and its relationship with

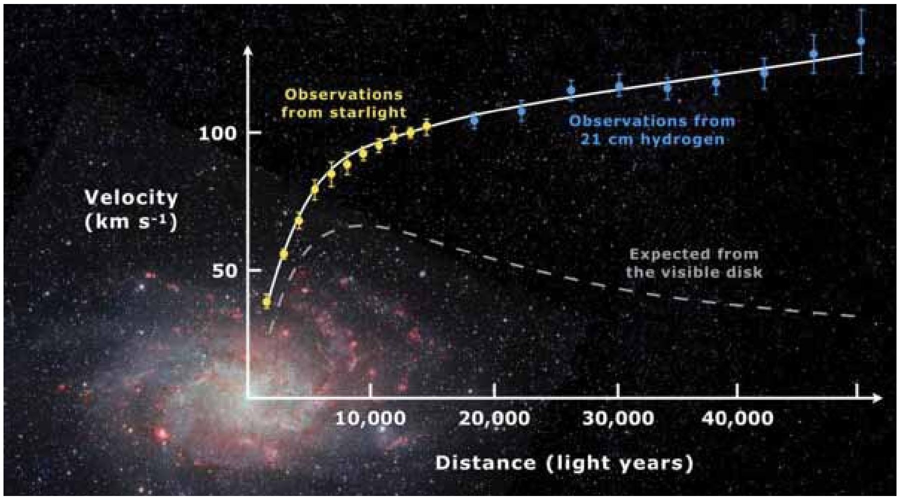

Figure 1. Measured rotation curve of spiral galaxy Messier 33 (points with error bars), and a predicted one from the distribution of the visible matter (gray line). The discrepancy between the two curves is usually accounted for by adding a dark matter halo surrounding the galaxy. Image credit: https://en.wikipedia.org/wiki/Galaxy_rotation_curve.

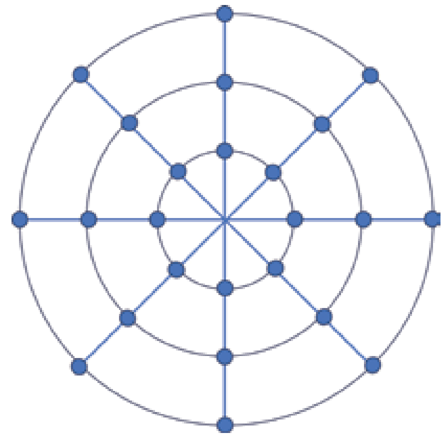

Figure 2. The "spider-web" central configuration with equal masses equally distributed in concentric circles about the center of mass. Note that neither geometric symmetry nor equal masses are required for central configurations. Configurations and velocities that form central configurations can be found for *any* choice of masses.

creation science. He cites the reluctance of most creation scientists to accept dark matter because of its use in ΛCDM. He asks how creationists handle rotation curves of spiral galaxies (without dark matter) and why the nuclear (inner) regions of these galaxies are subject to bound orbits but outer regions are not. He, rightly so, doesn't accept that "this is the way the world operates" is a satisfactory answer. Then he presents a dilemma for creationists who, again rightly so, insist on embracing design and stability in the cosmos: "Which is it? Did God create a stable world, or did He create an unstable world? Are creationists willing to sacrifice the stability argument in favor of a lesser argument for [a] relatively recent origin?"

A possible answer to this dilemma was introduced to the creation literature in Hartnett (2017), and we examine it here. This answer involves what are known as *central configurations*. Mathematician Donald Saari uses central configurations as an example of how rotation curves might be explained without dark matter. (See Saari, 2005; 2011; 2015; 2016) We will present Saari's explanation, a refutation of it, and an examination of this refutation along with lessons for and possible applications to creation cosmology.

The Importance (Necessity?) of N-Body Models: Saari

So far, we have addressed continuous mass distributions as approximations for the mass in a galaxy. Binney and Tremaine (1987, pp. 90–99) also discuss galactic dynamics as an *N*-body problem wherein the interactions between all bodies are considered explicitly. They point out the computational expense, i.e., having to evaluate $N \times (N-1) / 2$ interactions for N objects (with N on the order of 10^9!), and numerical integration difficulties, i.e., as the distance between objects becomes small, the forces between the objects become large. (See J.S. Bagla and T. Padmanabhan (1997) for a review of cosmological N-body simulations.)

Saari (2015) essentially sidesteps the computational expense of N-body calculations by developing analytic solutions of the Newtonian N-body problem posed as "central configurations" and uses these solutions to analyze the use of Equation (1) to estimate galactic mass. (For more details on central configurations, see Appendix A as well as Battye et al., 2003; Saari, 2005; Gibbons and Ellis, 2014; Moeckel, 2014 and 2014a; Barbour, 2020). He claims that these particular configurations reflect the properties used to derive Equation (1), at least as closely as discrete systems can. Those properties are: highly symmetric mass distributions, circular orbits, and the total gravitational attraction on each mass is directed toward the center of mass.

In his analysis, Saari introduces so-called "spider-web" central configurations, as shown schematically in Figure 2, where masses are equally distributed in angle in concentric circles about the center of mass (Saari, 2015 and 2016). For the general spiderweb configuration, the masses on a given ring are the same, but not necessarily the same as the masses on other rings. (In the case in Figure 2, the masses would have to be nearly equal for it to be a central configuration.) In the following, we will consider N masses arranged in n concentric rings with $2k$ masses per ring. The masses are located at the intersection of the rings and spokes placed at equal angular spacing. In this case, $N = 2nk$. (We note in passing that another mass can be located at the center of mass for a total of $N+1$, or $2nk + 1$, masses.) For large values of k, the mass distribution is highly symmetric. Saari proves a theorem that states that for any positive integers k and n and any choice of mass $m_j > 0$ (for j=1 to n), unique spacings between the concentric circles exist that form a spiderweb central configuration, and any positive multiple of these spacings is also a spiderweb central configuration.

Let r_i refer to the radius of the ith ring, as measured from the center of mass, and m_i refer to the mass of a single body on the ith ring. Assuming circular motion, the position and acceleration vectors, $\boldsymbol{r}$ and $\boldsymbol{r}_i''$ respectively, for these spiderweb configurations satisfy

$$\boldsymbol{r}_i'' = \lambda_i \boldsymbol{r}_i \quad (2)$$

A spiderweb configuration with the additional property that $\lambda_i = \lambda_j = \lambda$ for all i, j is called a "Saari configuration." In this case, Eq. (A.4) holds, repeated here as Equation (3).

$$\boldsymbol{r}_j'' = \lambda \boldsymbol{r}_j, j = 1, \ldots, N \quad (3)$$

Saari configurations rotate with constant angular velocity (like a rigid body), so the rotational speed at r is proportional to r, and the constant of proportionality can be shown to be $\sqrt{\lambda}$. Then Equation (1) becomes

$$M(r) = \frac{\lambda r^3}{G} \quad (4)$$

This means that the predicted mass distribution is always given by a cubic equation.

Saari works through an example of an $n = 100$ ring central configuration. He assumes the total mass on each ring adds up to one in order to simplify computations. He doesn't give the unique values for the ring spacings, but by the theorem cited above, we know they exist. Furthermore, by the same theorem, we know that any positive multiple of a central configuration is also a central configuration, so there is some multiple that will set the minimal spacing equal to 1, which he does. Given this, we know the mass enclosed by the j^{th} ring, located at r_j, is $M(r_j) = j$, and that the distance to r_j is at least j so $r_j \geq j$. This means that for arbitrary r, $M(r)$ is at best linear in r, i.e., $M(r) \leq r$, and *not* cubic like Equation (4). The cubic expression (Equation (4)) thus seriously overestimates the true $M(r)$ distribution, especially for the larger values of r, the outer edges.

Saari shows that problems arise whenever the predicted mass distribution significantly differs from the actual, including the predicted distribution you get from Equation (1) when a constant v_c (flat rotation curve) is encountered:

$$M(r) \approx Dr$$

In this case, too, the relative amount of mass at the edges is exaggerated. Hence, these predictions will also overestimate the actual mass.

Saari concludes: "According to the principles of scientific validation, unless new supporting arguments can be found, Equation (1) is not an appropriate way to predict $M(r)$ values for systems of N discrete bodies. Something in addition to, but probably different from, Equation (1) is needed…Thus, either the assumptions that are central in developing Equation (1) do not apply to discrete systems of N bodies, or the associated N-body solution can be expected to be a rotating rigid body causing exaggerated $M(r)$ predictions."

Saari (2015) states, "rigid body behavior can be expected to occur in portions of spiral galaxies as manifested by the nearly straight-line structure of the first part of the observed rotational velocity curves. With these observed values, the rotational structure conveys the flavor of a rigid body motion where separating particles on the galactic edges are being pulled along." What Saari calls the "first part" of the rotation curves is not the bulge which, according to the description of it above, does not rotate, but the part of the galaxy from the bulge to the beginning of the spiral arms. The "separating particles on the galactic edges" are the stars in the spiral arms and beyond. According to Saari, it is the "pulling along" of objects *on the galactic edge* that standard rotation curve analysis misses by assuming a continuous distribution of mass in a galaxy rather than treating the problem as a Newtonian N-body problem where individual interactions are tracked.

A Refutation of Saari's Conclusions: Kadowaki

Kadowaki (2018) takes issue with Saari's conclusions, claiming his analysis is "flawed." Kadowaki claims 1) "that Saari's *explanation* for the effectiveness of his counterexample is incorrect" (emphasis added) and 2) "that his counterexample [to the application of Equation (1)] fails to address the standard methods used to model galaxies…[and he has] misrepresented these methods."

Concerning his first claim, he points out that Equation (1) assumes a *spherically symmetric* mass distribution and argues that the reason it fails for central configurations is that they are *not* spherically symmetric. He claims its failure has nothing to do with the mass distribution being discrete as opposed to continuous. He claims further that if Saari's contention is correct, then a) Equation (1) *should* be a good approximation for a continuous non-spherical distribution, and b) Equation (1) *should not* be a good approximation for a discrete spherically symmetric distribution.

As a counterexample for a), Kadowaki provides an example that is a *continuous* distribution which, due to non-spherical symmetry, is *not* well-described by this equation. This example starts with a spherical potential and stretches the x-axis (x → kx), compresses the y-axis (y → y/k), and leaves the z-axis unchanged. He states, "The resulting potential will trace a distribution in which the rotation curves along these axes are significantly different and cannot all be consistent with Equation (1)."

As a counterexample for b), he provides an example of a spherically-symmetric but *discrete* distribution which *is* well-described by the equation. In this example, he uses a distribution of 3072 unit point masses on each of 20 equally spaced concentric spheres. He then shows that Equation (1) gives a good approximation to the actual mass and concludes that Equation (1) works in this case because of the approximate spherical symmetry.

Concerning Kadowaki's second claim (Saari's misrepresentation of methods to model galaxies), he notes, "Physicists and astronomers are, in fact, aware that galaxies are not spherical, and adjust their methods appropriately," and cites several examples from the literature, including the one used by Rubin and Ford (1970) to model galaxy M31. Recall that when discussing Potential Theory above, we pointed out nearly ten different shapes that have been modeled. Kadowaki presents a disk potential given by Binney and Tremaine (2011) that approximates spiderweb configurations using a continuous distribution and shows that for a particular spiderweb configuration (n = 50 rings, k = 100 spokes, $r_i = i$, and m =1 for all masses), the resulting potential gives a good approximation to the actual potential. He concludes that Equation (1) "does not play the central role that Saari contends" and that Saari uses an "oversimplified straw-man" of the standard methods of rotation curve analysis.

Furthermore, Kadowaki shows that astrophysicists have methods for estimating the impact of discreteness, which show this impact is negligible. In particular, he refers to Binney and Tremaine (2011), who estimate the amount of deviation a star will undergo as it crosses a galaxy and then estimate the number of crossings needed to have a deviation of the same order as its original velocity. They call the time for this number of crossings the relaxation time, below which the galaxy can be treated as collisionless and presumably well approximated by a smooth continuous potential. This relaxation time turns out to be more than 10^9 Myr, much longer than the (accepted evolutionary) age of the universe, so Kadowaki concludes smooth approximations are well-justified.

Kadowaki's overall conclusion is that "Saari has failed to make a compelling case for errors in standard methods for analyzing rotation curves—and, moreover, that his case relies on a misunderstanding of these methods and a severe underestimation of their complexity and scope. Thus, his skepticism about inferences drawn by these methods—namely, regarding the existence of dark matter—is entirely unwarranted."

Some Thoughts on Kadowaki's Refutation

Kadowaki admits that "Saari has successfully cast doubt on the ability of Equation (1) to accurately model large N-body systems in general…[and that] Saari's proof still shows that Equation (1) will fail to accurately model some distributions that lack approximate spherical symmetry." One conclusion that creation scientists can draw from this is that Equation (1) does have its limitations, which need to be considered before applying it to derive galactic mass from rotation curves.

Having said that, we now consider Kadowaki's refutation in some detail.

Edge Effects

As seen in the list that follows, Saari makes the point, more than once, that he is addressing stars near the outer edge of galaxies (emphasis added in all quotations):

- "dragging would tend to affect *bodies farther out*, which suggests the possibility of exaggerated mass predictions *for larger distances from the center* [of the galaxy]"
- "the observed flattening of rotational velocities implies *for large r values*…"
- "particles *on the galactic edges*"
- "this is particularly true *for larger r values on the outer fringes* of the solution."

Consider the following regarding these large r values (edges):

Binney and Tremaine (1987), Section 3.2, say: "Stars whose motions are confined to the equatorial plane of an axisymmetric galaxy have no way of perceiving that the potential in which they move is not spherically symmetric." The "Saari" (spider-web) configurations are confined to the equatorial plane of axisymmetric galaxies, so this applies to them.

From a more recent online textbook on galactic dynamics, Bovy (2023), we read:

- Section 8.2: "*At large distances*…the potential and force approach that of the spherical shell, which is the same as that of a point mass. This is a general rule for mass distributions of finite mass: *at large distances* their force becomes indistinguishable from that of a point of the same mass." (Emphasis added.)
- Chapter 8: "even for very flattened systems, like disk galaxies, the circular velocity is of a similar magnitude *as if the flattened mass were distributed_spherically*. So the circular velocity measures the mass distribution well even for such systems." (Emphasis added.) The motion of the Sun in the Milky Way is given as an example of assuming that the mass within the solar orbit is distributed spherically and the enclosed mass is shown to be "actually quite accurate!", when compared to the mass obtained when using a sophisticated mass model for the Milky Way.
- Section 8.1: "the radial profile may deviate from the pure exponential profile *in the inner or outer ranges of the disk*"
- Section 8.3.2: "the rotation curve of any finite-mass disk will tend to the Keplerian behavior $v_c \propto R^{-1/2}$ *at large distance*." (Emphasis added.)

It seems that for the objects Saari is considering, i.e., those on the outer edges of galaxies, Equation (1) should be a good model.

Kadowaki's Example of a Continuous, Non-Spherically Symmetric Distribution

Bovy (2023) claims that "many useful insights in galactic dynamics can be obtained by approximating mass distributions as easy-to-work-with spherical distributions." He offers a general rule that disk rotation curves "are largely set by the *overall* radial behavior of the mass distribution and only mildly dependent on its shape." (Emphasis added.) This seems to vindicate Saari's choice of Equation (1) as representative of *a* standard approach to rotation curves, even though it was derived assuming spherical symmetry, especially, as we just discussed, he applies it at the edges.

Tugging

The discussion in Binney and Tremaine (1987), Section 4.1, is apropos to Kadowaki's estimate of what he calls local variations. In this section, they address the case where two stars approach in a manner that changes the velocity of the approaching star by only a few percent ($\delta v/v \ll 1$) and the perturbing star is almost stationary during the encounter. They conclude that stellar encounters are unimportant for a star crossing a typical galaxy. This is *not* the case Saari considers. He considers stars *near the edge* of the spiral galaxy that are moving essentially parallel to one another, with the inner star moving faster than the outer star. Section 7.1 of Binney and Tremaine (1987) is applicable here. They consider a test star of mass M moving in a field of stars, each of mass m, considered individually. They show that a "dynamical friction" force is exerted on M by slower-moving stars, causing M to decelerate. By Newton's Third Law, there is an opposite force exerted on m, which will be Saari's "tugging" force.

Kadowaki's Spiderweb Counterexample

In order to show that Saari "fails to address the standard methods used to model galaxies…[and he has] misrepresented these methods," Kadowaki uses a disk potential taken from Binney and Tremaine (2011) to approximate spiderweb configurations. The example he uses was described above: 50 rings and 100 spokes evenly spaced with $r_i = i$ and $m_i = 1$ for all rings. The integral equation for the potential requires the surface density of the mass distribution, $\Sigma(R)$. He uses a coarse-graining procedure to approximate $\Sigma(R)$. But this surface density can be easily computed for the given configuration and shown to be inversely proportional to radius. Such a surface density is known as "Mestel's disk," whose circular velocity equation is "precisely analogous" to the circular velocity for a spherical system, i.e., Equation (1) (Binney and Tremaine, 1987). Even though Kadowaki's intention was to show how well the approximate and actual potentials agree, which he did, the example he uses is another example of where Equation (1) applies to a distribution that is not spherical but planar.

Concluding Thoughts on the Refutation

From Section 3.0 of Bovy (2023): "even though mass distributions can be quite far from spherical, <u>many of the properties of non-spherical distributions can be understood by approximating these distributions with some equivalent spherical distribution.</u> Similarly, many of the concepts that we will introduce in this chapter (like…*circular velocity*) <u>remain similar for non-spherical distributions</u>." (Italics in original; underline added.)

It seems Equation (1) *does* "play the central role that Saari contends" and that Saari's "oversimplified strawman" of the standard methods of rotation curve analysis is not really so oversimplified after all. Indeed, in the introductory section of Saari (2015), he refers to this as "*a* standard method" (emphasis added) and in the section titled "Standard Approach" he explicitly states, "There are more sophisticated ways to estimate $M(r)$, but Equation (1) is *a* standard approach." (Emphasis added.) Saari is aware of these more rigorous approaches but seems justified in using Equation (1), especially to describe the dynamics at the outer edge of galaxies. Nonetheless, Equation (1) should be used with caution. Saari's arguments show it should apply to the outer edges of galaxies but its use elsewhere needs to be justified.

Some Comments on Rotation Curves in General

Mass-to-light ratio

We read in Bovy (2023), Section 8.1: "To take observations of the surface-brightness profiles of disk galaxies and jump to the conclusion that the distribution of *stellar mass* in disks declines exponentially requires an additional assumption." This assumption is that stellar mass traces observed luminosity with a constant scaling called the *mass-to-light ratio*, which allows the observed luminosity to be converted to stellar mass. *Theoretical* mass-to-light ratios are computed based on evolutionary assumptions ("models for the relative proportion of different stars born from a molecular cloud in a star-formation event (the *initial mass function*) and models of stellar evolution"). He points out that "light is a very biased tracer of mass: the light in most bands is dominated by luminous, relatively high-mass stars (mass of the Sun or higher), while the mass budget is dominated by the lowest mass stars (far below the mass of the Sun). *It is therefore not obvious that the stellar mass profiles of disks are also exponential*." (Emphasis added.)

Magnetic Effects

Magnetic effects might influence the rotation speeds of gas in the outer regions. According to Nelson (1988): "The crucial point here is that where the rotation curves are anomalously high, the density of the HI gas drops to very low values, and this may significantly alter the energy balance between magnetic energy and rotational energy. Consequently, *in the outer parts of galaxies, the galactic magnetic field may play a primary role in large-scale gas dynamics, and the gas streamlines are not simple gravitational orbits*." (Emphasis added.)

Admittedly, this is an older article, but there have been more recent papers on this effect (which papers, by the way, reference this work by Nelson). See Beck and Wielebinski (2013), Khademi et al. (2023), and references therein. These magnetic effects could provide an explanation for the behavior of the outer portions of the galactic rotation curves.

A Creationist Conjecture

According to Saari (2005): "with appropriate initial conditions, any coplanar *N*-body central configuration can be placed into a circular…orbit that preserves the configuration; the motion keeps the shape while assuming different scale or rotation values." That is, if this configuration is *put* in circular rotational motion, it will maintain its shape. Saari (2005) also points out that for *any* choice of masses, we can find configurations and velocities that form central configurations. Neither geometric symmetry nor equal masses are required for central configurations, i.e., central configurations do not have to look like spider-web configurations. This leaves open the possibility that these galaxies were, in fact, *put* in (stable) central configurations when created, but deviated from them after the Fall and its effects on the cosmos.

On a cosmological scale, though not from a creationist perspective, Barbour (2020) introduces central configurations of the homothetic type, i.e., those encountered in collisions or "explosions" and applicable to three-dimensional motion rather than being limited to planar structures and motion like the Saari spiderweb central configurations discussed above (and see Appendix A). These have been proposed in models of the entire universe. For example, Gibbons and Ellis (2013) "consider a Newtonian cosmology for a universe made up of discrete gravitating particles. We do not assume either general relativity or fluid dynamics. We just use Newton's Laws of motion applied to a set of gravitating particles, with the particle interactions given by Newton's law of gravitational attraction." This approach should be welcomed by creationists and should be explored as a possible basis for creationist astronomy and cosmology.

Acknowledgements

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Appendix A. Central Configurations

Saari (2005) shows that central configurations (to be defined below) should be common in the Newtonian N-body problem, of which galaxies and the cosmos at large are examples. He starts with the usual equations of motion

$$m_j \boldsymbol{r}_j'' = \sum_{j\neq k} \frac{m_j m_k(\boldsymbol{r}_k - \boldsymbol{r}_j)}{r_{jk}^3}, j = 1, \dots, N \tag{A.1}$$

where m_j and $\mathbf{r}_j$ are the mass and position vector of j^{th} particle, $j = 1,\dots,N$; r_{jk} is the magnitude of $\mathbf{r}_k - \mathbf{r}_j$; the double prime indicates the second derivative with respect to time; and position is with respect to the center of mass. (Note that Saari usually works in units where the universal gravitational constant G = 1.) Saari defines the self-potential (negative of the potential energy)

$$U = \sum_{j<k} \frac{m_j m_k}{r_{jk}} \tag{A.2}$$

Then the equations of motion become

$$m_j \boldsymbol{r}_j'' = \frac{\partial U}{\partial \boldsymbol{r}_i} = \left(\frac{\partial U}{\partial x_i}, \frac{\partial U}{\partial y_i}, \frac{\partial U}{\partial z_i}\right), j = 1, \ldots, N$$

$$\boldsymbol{r}_j'' = \frac{1}{m_j}\frac{\partial U}{\partial r_j} \qquad \text{(A.3)}$$

Saari notes that it would be much simpler "if we could replace this equation with one that looks like"

$$\boldsymbol{r}_j'' = \lambda \boldsymbol{r}_j, j = 1, \ldots, N \qquad \text{(A.4)}$$

He says further that "for *any* choice of masses, choices of configurations and velocities can be found that allow this…replacement." (Saari, 2005, p. 35; emphasis added.) He then defines a *central configuration*:

The N-particles form a central configuration at time t if there exists a scalar λ so that

$$\lambda m_j \boldsymbol{r}_j = \frac{\partial U}{\partial r_j}, j = 1, \ldots, N \qquad \text{(A.5)}$$

In words, "A central configuration occurs whenever the particles line up in the particular fashion where each particle's position vector is the same scalar multiple of the particle's acceleration vector…[T]hese configurations tend to arise whenever the same configuration is rigidly preserved during the motion, or whenever the N-body gravitational pressures force a 'balancing' among the limiting behaviors of the particles." (Saari, 2005, p. 35)

If a configuration is preserved during motion, it is called homographic motion. A special case of homographic motion is where the solutions behave like a rotating rigid body. If the particles are constrained to move along straight lines passing through the center of mass of the system, the motion is called homothetic.

Saari shows that:

- Galaxies within a group of galaxies tend to form central configurations, and
- Particles moving in a plane, behaving like a rigid body, *must* form a central configuration

Saari defines I as one-half the polar moment of inertia. For a central configuration:

$$I = \frac{1}{2}\sum_{j=1}^{N} m_j \boldsymbol{r}_j^2 \qquad \text{(A.6)}$$

Saari then shows that the constant, λ, is given by:

$$\lambda = -\frac{U}{2I} \qquad \text{(A.7)} \qquad \text{(A.7)}$$

Furthermore, for central configurations that rotate like a rigid body, each particle's trajectory is given by

$$z_j(t) = a_j e^{i\omega t}$$

or

$$z_j''(t) = -\omega^2 a_j e^{i\omega t}$$

This has the form of Equation (4), so we can see that in this case, $\lambda = -\omega^2$.

Saari (2005) proves a theorem that says that for a central configuration, if there is rotation, then the motion is coplanar, i.e., the particles must be in a plane, and if the configuration is not coplanar, there must be no rotation and the motion is homothetic, i.e., the particles are constrained to move along straight lines passing through the center of mass of the system.

Additional insight into central configurations is provided by Barbour (2020). He defines the Newton potential, V_{New}, the root-mean-square length, l_{rms}, and the mean harmonic length, l_{mhl}:

$$V_{New} = -G\sum_{a<b}\frac{m_a m}{r_{ab}}$$

$$l_{rms} = \frac{1}{M}\sqrt{\sum_{a<b} m_a m_b r_{ab}^2}$$

$$\frac{1}{l_{mhl}} = \frac{1}{M^2}\sum_{a<b}\frac{m_a m_b}{r_{ab}} = -\frac{1}{M^2}V_{New}$$

He then defines the *shape complexity*

$$shape\ complexity = \frac{l_{rms}}{l_{mhl}}$$

$$= -\frac{l_{rms}V_{New}}{M^2}$$

In these equations, M is just the total mass in the system. The shape complexity is a pure number and depends only on the mass ratios of the particles and the shape of their distribution. The two factors that define the shape complexity change in different ways if two or more particles move closer to each other. For a system with many particles, l_{rms} hardly changes, but V_{New} changes considerably.

Barbour also defines the *shape potential*, V_{shape}, as the negative of the shape complexity. He attributes the expression "shape potential" to N-body specialists and says that central configurations can exist only where complexity has an extremum (maximum, minimum, or saddle point). Basically, the same mathematical formula characterizes both the structure (complexity) and the shape potential (the potential for change through gravity).

Barbour notes that exactly symmetric central configurations are rare and atypical. He also notes that as the number of particles increases, the number of central configurations increases rapidly and might form a continuum of possible shapes, i.e., *central configurations might not be rare*.

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