AN ALTERNATIVE MODEL FOR THE ROTATION OF SPIRAL GALAXIES: THE CONNECTIONS AMONG SHAPE, KINEMATICS AND EVOLUTION

Mario Everaldo de Souza
Universidade Federal de Sergipe, Departamento de Física
e-mail: mariodesouza.ufs@gmail.com
Av. Marechal Rondon, s/n, Campus Universitário, Jardim Rosa Elze
49100-000, São Cristovão, Sergipe, Brazil

Abstract

It is proposed that the arms of spiral galaxies are formed by the continuous outflow of matter from their centers. It is then shown that the ratio between the radial and tangential velocities of the outflow is the parameter responsible for the logarithmic spiral structure of spiral galaxies. The fitting of some spiral galaxies to the model allows the calculation of the radial velocities of matter in these galaxies and such values completely agree with the observational data. An approximate general equation is proposed for the description of the arms of spiral galaxies with or without bars. Some important consequences are discussed with respect to dark matter, galactic evolution and cosmology. It is concluded that a quantitative representation of the dynamics of the spiral galaxies can be entirely represented with data on their formation without any need to use the far-reaching conjecture of dark matter. We finally indicate that this conclusion is fully in agreement with the absence of dark matter inferred from Santilli's IsoRedShift within the inhomogeneous and anisotropic inner galactic medium that light has to traverse before reaching intergalactic spaces, as well as with the recent demise of symmetries and other recent advances.

Keywords: Rotation models of spiral galaxies; Rotation of spiral galaxies; Spiral galaxies; Spiral structure; Galactic evolution; Santilli IsoRedShift; Dark matter.

Introduction

The current status quo for the rotation of spiral galaxies is still based on the density wave theory which states that the matter of the disk becomes distributed in spiral arms due to the action of a wave-like perturbation in the form of quasi-steady global modes of the disk ([1],[2],[3]). These three references are just examples of a long list of proposals within the same general framework. Other approaches defend that the spiral structure is a short-lived, transient phenomenon triggered by gravitational instabilities. Two of many references in this line are Goldreich & Lynden-Bell [4], and Julian & Toomre [5].

A quite simple argumentation against the density wave theory is that according to this theory we would have to have many spirals with 3, 4, and even 5 arms. Observations, however, have shown that almost all spirals have only two arms.

A very recent study by Foyle et al. [6] based on observations of 12 spiral galaxies discard the density wave theory in its simplest form as being an "important aspect of explaining spirals in large disk galaxies", but the authors wrongly conclude that the spiral structure is not a long-lived phenomenon.

We present an alternative model for the description of spiral galaxies based on the outflow of matter from their cores and show that the spiral structure is inherent to the existence of the galaxy. Outflows of matter from the centers of galaxies have been reported since a long time ago. Let us present some examples. Very recent data [7] of NGC 6240, which is considered a typical protogalaxy show that "approximately 70% of the total radio power at 20cm originates from the nuclear region $(\leq 1.5 kpc)$, of which half is emitted by two unresolved $(R \leq 30 pc)$ cores and half by a diffuse component. Nearly all of the other 30% of the total radio power comes from an arm-like region extending westward from the nuclear region". NGC 2992 presents a jet-like structure and a circum-nuclear ring [8]. Falcke and Biermann [9] report that there is a large scale emission-like jet going outward from the core of NGC 4258 with a mass of about 4×10^{35} kg and with a kinetic power of approximately 10^{42} ergs/s and expansion velocity of about 2000km/s. Brunthaler et al. [10] report the first superluminal jet with a velocity of about 1.25c in the Seyfert spiral galaxy III Zw 2. For superluminal as well as subluminal speeds within physical media verifying causality laws in view of the universal Lorentz-Poincaré-Santilli (LPS) isosymmetry for interior dynamical problems, one can see Ref. [11], and the comments in the Concluding Remarks.

Balmaverde and Capetti [12] have reported in 2006 that "Considering the radio structure, several objects of our CoreG sample have a radio-morphology with well developed jets and lobes: UGC 7360, UGC 7494 and UGC 7654 are FR I radio-galaxies part of the 3C sample (3C 270, 3C 272.1 and 3C 274), while in the Southern sample we have the well studied radio-galaxies NGC 1316 (Fornax A), a FR II source, NGC 5128 (Cen A) and IC 4296. A literature search shows that at least another 11 sources have extended radio-structures indicative of a collimated outflow, although in several cases this can only be seen in high resolution VLBI images, such as the mass scale double-lobes in UGC 7760 or the one-sided jet of UGC 7386". Sturm et al. [13] have just reported massive molecular outflows from the centers of ultraluminous infrared galaxies (ULIRGs). As the authors state the terminal velocities in some of these outflows exceed 1000 km/s "and their outflow rates (up to ~ 1200 solar masses per year) are several times larger than their star formation rates". Middleberg et al. [14] report radio observation of Seyfert galaxies NGC 7674, NGC 5506, NGC 2110 and Mrk 1210, and conclude that "Our results confirm and extend earlier work showing that the outward motion of radio components in Seyfert galaxies is non-relativistic on pc scale. We briefly discuss whether this non-relativistic motion is intrinsic to the jet-formation process …." Muñoz-Tuñon and Beckman [15] analyze the consequences of mass outflows in the circumnuclear zones of galaxies. They have found "in addition to a ring structure in the gas, there is often measurable expansion with higher radial velocities occurring near the nucleus" and also they show that "radially progressive bursts of star formation can account for a wide range of these observed phenomena and could be related to the presence of *liners* in the interstellar medium close to the nucleus." Last April Alatalo et al. [16] have reported the discovery of an AGN-Driven Molecular Outflow in the early-type galaxy NGC 1266 which is classified as an S0 without arms. The molecular outflow has a molecular mass of 2.4×10^7 Msuns. As the authors observe "The star formation in NGC 1266 is insufficient to drive the outflow, and thus it is likely driven by the active galactic nucleus (AGN)". A very important work that shows the initial formation of spiral arms in a galaxy is the paper of Stark et al. [17] entitled **The formation and assembly of a typical star-forming galaxy at redshift $z \approx 3$.** The authors report studies of a galaxy about 2-3 Gyr after the Big Bang. One of the very significant results of the work is the regular, bi-symmetric velocity field revealed by the O III emission lines measurements. Examining the velocity field in more detail, the authors extracted a rotation curve with a circular velocity of about 67 km/s. Figure 1 of the article clearly shows an arm-like structure. Mark Swinbank who is one of the authors, commenting on the paper on the site EurekAlert! [18], has said that "The distribution of gas seen with our amazing resolution indicates we are witnessing the gradual build-up of a spiral disk with a central nuclear component". Recently, in 2001, Wilson et al. [19], using high resolution X-ray observations with Chandra, have managed to solve the puzzle concerning the anomalous ghostly opposite arms of M106 (NGC 4258) which are dominated by young stars : they are jets that originate in the nucleus of the galaxy.

Another aspect of the subject is provided by analyses of metallicity gradients in spiral galaxies. The NED/IAC/Caltech document [20] on this issue is a thorough text which takes into account the works of many researchers. The text shows that the data for the Milky Way are in line with those from other spirals, and that the metallicity data expressed in terms of $12+\log(O/H)$ decreases with the distance from the centers of spirals, clearly showing that their disks are younger than their bulges and that the hydrogen has its origin in the centers of galaxies.

Taking a closer look at the morphologies of some galaxies we can clearly see jets/arms coming out or their nuclei. It is the case of some galaxies classified as peculiar galaxies. All pictures of UBVR images (UGC ´s and VV 114*) shown below are credited to Hibbard, Liu & Armus [21]. A very enlightening image is that of UGC 04264* (Fig 1) which shows two young arms in the lower spiral galaxy. The lower arm is not affected by tidal forces.

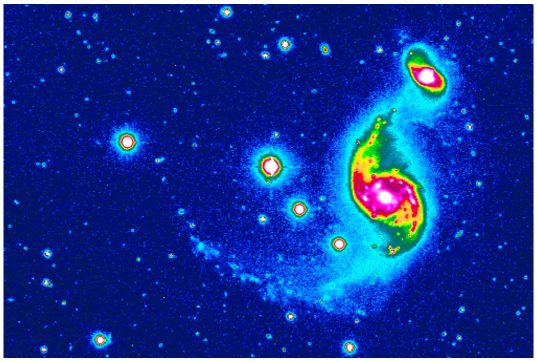

Fig.1: UBVR image of UGC 04264*. The arms in the spiral galaxy are young and the lower arm is not affected by tidal forces from the interacting galaxies.

Still another clear example is the image of UGC 06748* (Fig. 2) where we can observe young arms in the spiral galaxies being formed. Observe that the top arm of the left galaxy and the right arm of the middle galaxy do not suffer tidal forces.

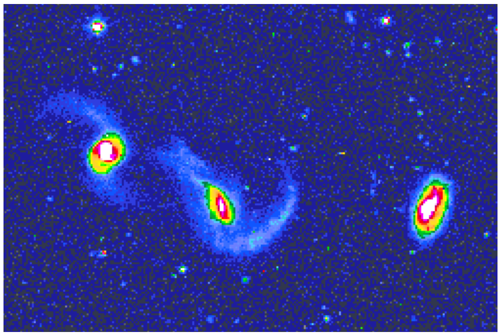

Fig. 2. UBVR image of UGC 06748*. On the left we see a pair of interacting spiral galaxies with young arms.

The remarkable image below (Fig. 3) of UGC 08929* reveals the formation of a very young arm in the spiral galaxy. The arm/jet is just beginning to curve and on the other side we already see some protuberance being formed.

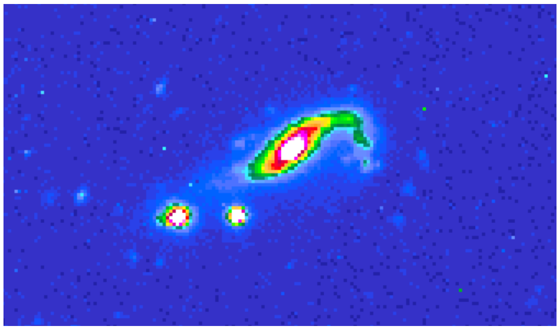

Fig. 3. UBV image of a very young arm just beginning to curve. Observe the protuberance on the opposite side.

Fig. 4 below is another quite remarkable UBVR image which shows spiral arms just being formed. We clearly notice that the upper arm is much more developed than the lower arm.

It is worth mentioning that along with outflows of gases there are also inflows of gases towards the centers of galaxies. A particular inflow is actually the result of a previous outflow because if the outflow velocities are smaller than the escape velocity from the very massive center, the gases just fall back and suffer inflows. This happens a lot in barred spirals.

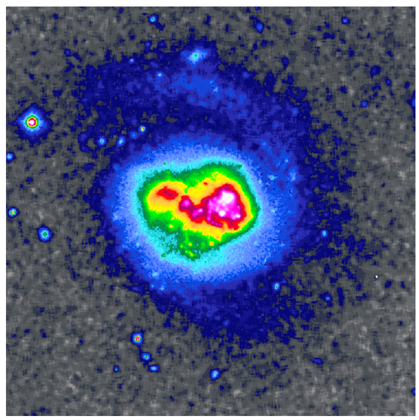

Fig. 4. Spiral arms just being formed in spiral galaxy VV 114* (Arp 236).

Closing this introduction let us address the mathematical description of the arms in spiral galaxies. It is well known that the arms of spiral galaxies are excellently described by a logarithmic spiral of the form

$$r = ae^{b\theta} \tag{1}$$

as proposed by Danvar [22]. The constants a and b are just constants which can be appropriately chosen.

2 The model

Taking into account what was shown and discussed above this work proposes that the spiral arms are formed by the shedding of matter from the nuclei of spiral galaxies. This is actually an old idea, proposed in 1964 by Oki et al. [23]. So, let us consider that a certain extended mass of gas m is ejected from the bulge of the galaxy with a radial velocity v_r as is shown in Fig. 5. In the bulge the mass m was rotating with an angular velocity Ω. When it leaves the bulge at a later time v_θ is not affected by the radial driving forces that cause the shedding of matter, and as it is shown below the mass keeps its angular momentum maintaining the tangential velocity approximately constant. Let us recall again that m is not pointlike. The Milky Way and other galaxies show that the mass m frequently has the form of an arc of matter which gets approximately distributed along a spiral so that we have an equation of the form for the angular momentum of m

$$mRv_\theta = \sum_i m_i r_i v_{\theta_i} \tag{2}$$

where R is the radius of the bulge, v_{θ_i} are the velocities of the different parts of the extended mass m which are located at r_i, just after having left the bulge. We notice that after having left the bulge the mass m can continue with an average v_θ given by

$$v_\theta = \frac{1}{mR}\sum_i m_i r_i v_{\theta_i} = \sum_i \left(\frac{m_i}{m}\right)\left(\frac{r_i}{R}\right) v_{\theta_i} \tag{3}$$

in which, since $m_i / m < 1$ and $r_i / R > 1$, v_{θ_i} can thus have values around v_θ. We obtain more detail on this if we analyze the behavior of the kinetic energy. Just before leaving the bulge the mass m (in the form or an arc, for example) has the kinetic energy

$$K = \frac{1}{2} m\left(v_r^{\,2} + v_\theta^{\,2}\right) \tag{4}$$

and just after having left the bulge the mass m has the kinetic energy

$$K = \frac{1}{2}\sum_i m_i \left({v_{r_i}}^2 + {v_{\theta_i}}^2 \right) \tag{5}$$

Disregarding the small variation of the gravitational potential, K is conserved and thus we have

$$\frac{dK}{dt} = \sum_i m_i \left(v_{r_i} \frac{dv_{r_i}}{dt} + v_{\theta_i} \frac{dv_{\theta_i}}{dt} \right) = 0 \tag{6}$$

whose solutions are

$$v_{r_i} \frac{dv_{r_i}}{dt} + v_{\theta_i} \frac{dv_{\theta_i}}{dt} = 0 \tag{7}$$

with $\frac{dv_{\theta_i}}{dt} \neq 0$, $\frac{dv_{r_i}}{dt} \neq 0$, and

$$\begin{cases} v_{r_i} = const \\ v_{\theta_i} = const \end{cases} \tag{8}$$

In the case of (7) $\frac{dv_{r_i}}{dt}$ and $\frac{dv_{\theta_i}}{dt}$ have opposite signs. The analysis of Shetty et al. [24] on streaming of matter in M51 clearly shows that v_{r_i} and v_{θ_i} vary together about their mean average values.

However, observations have shown that Nature prefers the solution given by (8), and our fittings below show that this is indeed the case. The reason for this lies in the fact that the driving forces that shed matter outward are radial forces and, hence, do no work in the direction of $\vec{v}_{\theta_i}$. The simple arguments above show that the constancy of the tangential velocity of spiral galaxies is directly related to the ejection of matter from their bulges and to the conservation of mass, energy and angular momentum, and thus, there is no need for dark matter. Thus

$$v_\theta \approx const \tag{9}$$

throughout the galaxy.

After having left the bulge, after a time interval Δt, the center of mass of the extended mass m will be located at point P, at a distance r from the center O (Fig. 5), and since v_θ remains approximately constant, we have

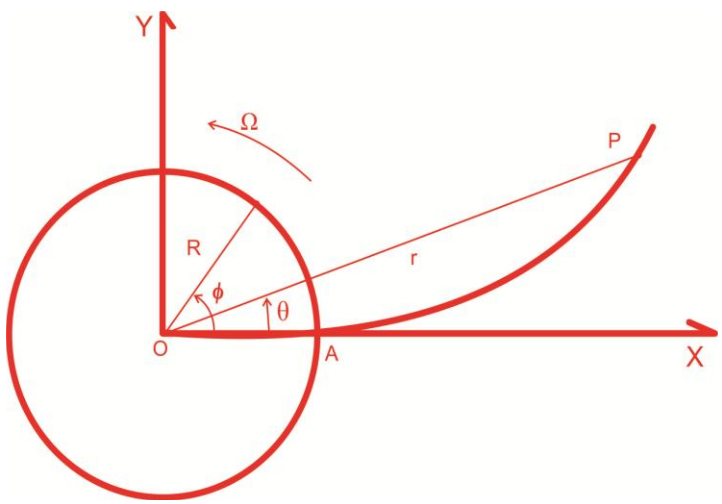

Fig. 5. While the bulge radius sweeps an angle ϕ, the mass m makes an angle θ in its displacement from A to P.

$$r\omega = r\frac{d\theta}{dt} = R\frac{d\phi}{dt} = R\Omega = v_\theta \tag{10}$$

where ϕ is the angle that the center of mass of m would have if it had not been ejected from the bulge, that is, it is the angle that the bulge made during the time interval Δt. Thus, (10) yields

$$\omega = \frac{R\Omega}{r} \tag{11}$$

From (10) we also obtain

$$d\theta = \omega dt = \frac{R\Omega}{r} dt = \frac{v_\theta}{r v_r} dr \tag{12}$$

where we have made use of the fact that $v_r = \frac{dr}{dt}$.

The first approximation is to consider the radial velocity v_r approximately constant. In this case the integral of (12) is just

$$r = Re^{\Gamma\theta} \tag{13}$$

where $\Gamma = \frac{v_r}{v_\theta}$. (13) is Danvar equation, but now we see that Γ is a very important parameter, directly related to the kinematics of the galaxy. It was deduced by de Souza quite some time ago [25,26]. Substituting (13) into (11) we obtain

$$\omega = \Omega e^{-\Gamma\theta} \tag{14}$$

and thus the arms lag the bulge exponentially with respect to θ. Since $\Omega = \frac{d\phi}{dt}$,

$$\phi = \frac{1}{\Gamma}\left(e^{\Gamma\theta} - 1\right) \tag{15}$$

This relation is important because knowing the maximum θ for a certain spiral arm we can find the maximum value of ϕ and find out how much the bulge rotated since the beginning of the formation of the spiral arms. Of course, this is very important for studying galactic evolution. We can also define the lagging angle $\Psi = \phi - \theta$ (Fig. 6).

It is important to mention that the beginnings of the formations of the two arms may occur at different times, and the arms can have different radial velocities. That is why there are asymmetric spirals with an arm much more developed than the other one. There are even spiral galaxies with a single arm such as NGC 4725.

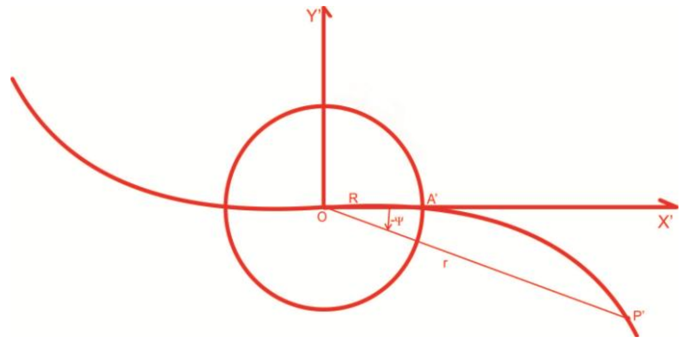

Fig. 6. The lagging angle $-\Psi = \theta - \phi$ which is measured with respect to the initial stream of matter, across a diameter of the bulge by an observer corotating with the bulge.

In the data of Ganda et. al. [27] of 18 galaxies we find galaxies where v_r increases slightly with r, although in most of them v_r decreases slightly with r. Therefore, our approximation above is quite justified. If we consider the variation in v_r with the gravitational field we should also consider other effects such as interaction between consecutive arms, and this is a very complex effect and is hard to be taken into account.

3 Application of the model to some spirals

We begin the application of (13) to the grand design galaxies M51 and M74 and to the barred spiral NGC 1300. In all galaxies below the data points were visually captured with the use of the software *plot digitalizer*. Since we are dealing with the logarithm of a fraction in the fitting of Γ, the error bar is quite small because the logarithm smoothes out errors. Thus we estimate for the fitted values of Γ an error bar of about 1-2%.

3.1 M51

We followed the black dust lane of the lower arm in Fig. 7 below (the arm that goes towards M51B). We took the lagging angle $-\Psi$ with respect to the beginning of the arm, that is, with respect to $\phi = 0$, and thus, $\theta = -\Psi$ in intervals of 30^o, and measured the corresponding values of r in terms of the bulge radius R.

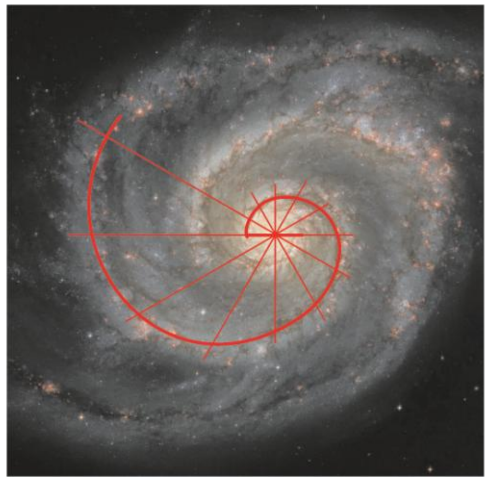

Fig. 7. The considered data points were close to the above spiral, following a dust lane (NASA/HST photo).

The obtained values for r/R and their corresponding θ and Γ are listed in Table 1. The average value of Γ is 0.37, and thus $v_r / v_\theta = 0.37$.

On p. 1151 of the paper *Kinematics of spiral-arm streaming in M51*, Shetty et al. [24] present a detailed analysis of v_r and v_θ in terms of an arm phase angle defined by the authors. It is clearly shown that v_r values vary around 50km/s and v_θ have values around 150km/s, and thus the ratio $\Gamma = \frac{v_r}{v_\theta} \approx 0.30$ is quite close to the above value of $\Gamma = 0.37$. As we will see below this is, actually, the worst discrepancy.

Table 1. The calculated values of Γ for spiral galaxy M51.

$\theta = -\Psi$	r/R	Γ
30^o	**1.23**	**0.39**
60^o	**1.45**	**0.36**
90^o	**1.82**	**0.38**
120^o	**2.09**	**0.35**
150^o	**2.49**	**0.35**
180^o	**2.86**	**0.34**
210^o	**4.45**	**0.41**
240^o	**4.82**	**0.38**

3.2 M74

In this case we chose the spiral arm shown in Fig. 8 and considered points corresponding to bright stars around the middle of the arm. We took the lagging angle as in the case of M51.

Fig. 8. The fitted spiral of NGC 628 considered for the calculation. The spiral is along the bright patch of the arm (NASA/HST photo).

Table 2. The calculated values of Γ for spiral galaxy M74.

$\theta = -\Psi$	r/R	Γ
60^o	**1.38**	**0.31**
90^o	**1.75**	**0.36**
120^o	**2.25**	**0.39**
150^o	**2.63**	**0.37**
180^o	**3.13**	**0.36**
210^o	**3.63**	**0.35**
240^o	**3.88**	**0.32**
270^o	**4.25**	**0.31**
300^o	**4.63**	**0.29**

According to Kamphuis & Briggs [28] v_θ for NGC 628 (M74) is about 200 km/s and according to Ganda et al. [27] its v_r is about 70 km/s, and thus, $\Gamma \approx \frac{70}{200} = 0.35$ which is quite close to our calculated values above (Table 2) whose average is 0.34.

3.3 NGC 1300

The considered value for R was half of the diameter between the ends of the dust lanes in the bright nucleus. Then this line was displaced to the beginning of the spiral arms for the calculation of Γ (Fig. 9). As in the previous examples, intervals of 30^o were used along the dust lane of the arm.

Table 3. The calculated values of Γ for the barred spiral galaxy NGC 1300.

$\theta = -\Psi$	r/R	Γ
60^o	**1.31**	**0.52**
90^o	**1.74**	**0.53**
120^o	**2.34**	**0.54**
150^o	**3.00**	**0.42**

The calculated values are shown in Table 3. Above 150^o Γ decreases too much, probably because, due to its shape, the arm is attracted a lot towards the bar. The average of the calculated values below is 0.50.

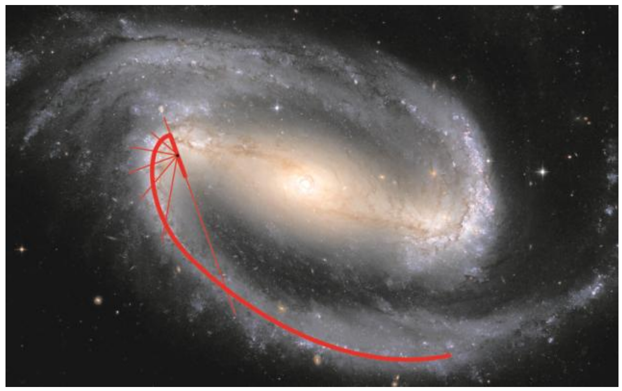

Fig. 9. We considered the dust lane of the lower arm of NGC 1300 for the calculation of Γ (NASA/HST photo).

According to Aguerri et al. [29] $v_\theta \approx 220\,\mathrm{kms}^{-1}$ and Lindblad et al. [30] report a v_r in the arms of the order of 120kms^{-1}, yielding, thus, a value of $\Gamma \approx 0{,}545$ which is very close to the calculated values above.

3.4 NGC 4030

In this case, since the bulge is very fuzzy, we considered angular differences with respect to a baseline across the center of the nucleus. Fig. 10 below shows the arm which was considered and Table 4 presents the results whose average value is 0.37.

Table 4. The calculated values of
Γ for the spiral galaxy NGC 4030.
r_b means the distance to the center
of the nucleus across the baseline.

$\theta = -\Psi$	r / r_b	Γ
30^o	**1.38**	**0.40**
60^o	**1.46**	**0.36**
90^o	**1.77**	**0.36**
120^o	**2.15**	**0.37**

Ganda et al [27] report a value $v_r \approx 90$ km/s and Mathewson & Ford [31] say that v_θ is about 236 km/s, and, thus, $\Gamma \approx 0.38$ which is quite close to the above calculated average value.

Fig. 10. The fitted arm of the spiral NGC 4030 (Penryn, California photo).

3.5 NGC 1042

We performed the fitting in the longer arm, as shown below in Fig. 11 and measured the ratios r/R in intervals of 30^o. The calculated values for Γ are listed in Table 5. Their average value is about 0.69.

Table 5. The calculated values of Γ for the spiral galaxy NGC 1042.

$\theta = -\Psi$	r/R	Γ
60^o	**2.0**	**0.66**
90^o	**3.0**	**0.70**
120^o	**4.6**	**0.73**
150^o	**5.6**	**0.66**

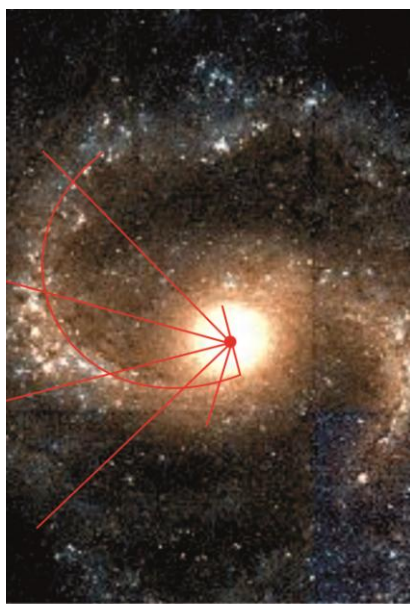

Fig. 11. The arm of NGC 1042 considered in the fitting (NASA/HST photo).

Ganda et al. [27] report $v_r \approx 50\,\mathrm{kms}^{-1}$ and Kornreich et al. [32] present $v_\theta \approx 69.4\,\mathrm{kms}^{-1}$ which yield $\Gamma \approx 0.72$ that is very close to our average value above. Therefore, this galaxy is more like a barred spiral.

3.6 NGC 4254

This galaxy is quite asymmetric and offered some important features for testing our model because of its three arms.

We began the fitting by arm B (Fig.12) and found, initially, for Γ, a value of about 0.33, very different from 0.53, the value calculated from the data taking into account the value for $v_r \approx 80\,\mathrm{kms}^{-1}$ of Ganda et al. [27] and the value for v_θ of 150 km/s from Kornreich et al. [32]. But then we found out that the reported value of $v_r \approx 80\,\mathrm{kms}^{-1}$ of Ganda et al. [27] refers to arm A in Fig. 12. Then we performed the fitting of arm A and found for Γ the average value of about 0.51 which is quite close to the observed value. **And thus, Eq. (13) is indeed a universal equation for spirals that obey Danvar equation**. Tables 6, 7 and 8 show the fittings for the different arms.

Fig. 12. The three arms of NGC 4254 considered for the fitting (Photo by Teresa O´Keefe and Jeff Lawrey/Adam. Block/NOAO/AURA/NSF).

Table 6. The fitted values for arm A of NGC 4254.

$\theta = -\Psi$	Γ
30^o	**0.49**
60^o	**0.50**
90^o	**0.53**
105^o	**0.51**

Table 7. The fitted values for arm B of NGC 4254.

$\theta = -\Psi$	Γ
60^o	**0.32**
90^o	**0.32**
120^o	**0.33**
150^o	**0.35**
180^o	**0.34**
210^o	**0.33**
240^o	**0.33**

Table 8. The fitted values for arm C of NGC 4254.

$\theta = -\Psi$	Γ
30^o	**0.31**
60^o	**0.32**
90^o	**0.37**

And now we can understand why this galaxy is so asymmetric: arm A has a larger radial velocity than arms B and C, and has Γ values of arms of barred spirals. With the above average values of Γ ($\Gamma_B \approx 0.33$, $\Gamma_C \approx 0.33$) for arms B and C we find that their radial velocities are approximately equal to 49.5 kms^{-1} which is much smaller than the radial velocity of arm A.

4. Discussion of results

4.1 Connections among shape, kinematics and evolution

We clearly see that the results are consistent and the parameter b of the Danvar equation is the ratio $\Gamma = v_r/v_\theta$ and is, thus, directly connected to the kinematics of the galaxy. This means that the shape of a spiral galaxy is directly connected to its kinematics and evolution. Young spiral galaxies are small and old spiral galaxies are large (unfolded). **A spiral galaxy unfolds itself from the inside out throughout time up to the exhaustion of the mass of its nucleus.** And it does not get tightly wound as a consequence of the unfolding and winding because of the radial velocity v_r. Of course, the bulge should diminish slowly with time since its mass is shed outward. The Milky Way is still shedding matter outwards and there is a lot of mass in its center yet, and so it will keep on going during quite a while, probably a couple of billion years.

The calculation of the parameter Γ for a galaxy from the shape of its arms provides important information on its kinematics and will be very useful for the study of spiral galaxies.

The above calculations and results mean that if v_θ varied too much with r spiral galaxies would not exist at all.

We immediately observe that most galaxies have not rotated much because of the following argumentation. Considering the ends of the arms of a spiral and taking the angular difference between them we obtain a certain $\Delta\theta$, and so we have the approximate relation

$$\frac{R_D \Delta\theta}{2R_D} \sim \frac{v_\theta}{v_r} = \Gamma^{-1} \tag{16}$$

and, thus, $\Delta\theta \sim 2\Gamma^{-1}$. For M51A, for example, $\Delta\theta \sim 2 \times 0.37^{-1}$ rad = 5.4 rad = 1.72 π rad. Taking a look at its photo we observe that it has barely completed a full turn. The same holds for M74, for which $\Delta\theta \sim 2 \times 0.31^{-1}$ rad = 6.45 rad = 2.05 π rad. For NGC 1300 we obtain the value of $\Delta\theta \sim 2 \times 0.5^{-1}$ rad = 4 rad = 1.27 π rad, which is very consistent.

4.2 Distinction between barred and non-barred spirals

We observe that with respect to the tangential velocity, barred spirals have larger radial velocities (expansion velocities) than non–barred spirals and that is why their spiral arms are more open, that is, less tightly wound. Analyzing more galaxies we can establish what the minimum value of Γ is for a barred spiral.

4.3 Studies on asymmetry in spiral galaxies

The measurement of Γ by means of the spiral arms will enable us to study what is going on in asymmetric galaxies as we did above for the case of NGC 4254.

4.4 Consequences for the Milky Way

The tangential velocity of the Milky Way is about $220 km/s$ [24] and at our galactic longitude $v_r \approx 130 km/s$ [24], so that $\Gamma \approx 0.59$ and, thus, the Milky Way is probably a barred spiral. And now, knowing its Γ we can calculate the shape of its arms.

4.5 Cosmological consequences

We should readdress the time of galaxy formation because, according to the above results, galaxies were formed much earlier than what is presently considered. And since spirals were small when they were young, they probably were formed from quasars which is an old idea proposed by de Souza [34,36] and Arp [35].

4.6 Consequences for dark matter

We observe that the dynamics of the disk of a spiral galaxy is mainly dictated by v_r, v_θ and its ratio Γ, and v_θ is approximately constant in the disk because the driving forces that shed matter outward are radial forces and do no work on the perpendicular direction, and thus, cannot change v_θ. Therefore, dark matter plays no role in the dynamics of a spiral galaxy. Actually, if dark matter existed, Γ would not be approximately constant and, thus, spiral galaxies would not exist at all.

4.7 The AGN engine

The values of Γ, v_θ and v_r above presented can be of some help in the search for the nature of the AGN engine that powers spiral galaxies.

4.8 Flocculent and ring spiral galaxies

Taking into account what was presented above we can say that flocculent galaxies are probably formed when the shedding of matter is done mainly in the form of very large arcs of matter and thus the spiral structure gets messed up. In the case of ring galaxies, they should occur when the ejection of matter happens in the form of rings.

4.9 Irregular galaxies

Irregular galaxies are formed when the shedding of matter outward is done in a more chaotic way. In this case there may not exist any bipolar flow either. This means that in this case the outward flow has characteristics of an explosion.

5 Spirals which do not obey Danvar equation

This is the case of galaxies such as NGC 772. In this case the radial velocity is too high, much larger than the tangential velocity. It is a much more complex system and, of course, our simple approximation above cannot be valid.

6 Conclusion

We have presented a new model for the formation of the arms of spiral galaxies which is directly connected to their kinematics and evolution in which the Danvar equation is dynamically derived. The application of the model to spiral galaxies shows full consistency with available experimental data. We have then discussed some important consequences of the model with respect to the dynamics, evolution and the age of formation of spiral galaxies. The results reached in this paper show the lack of any need of far reaching conjectures, such as that of dark matter, to explain the interior dynamics of galaxies, since all data are fully representable via data on their formation. The absence of dark matter reached in this paper is independently confirmed by the discovery of anomalous redshift of light propagating within gaseous media without any relative motion between the source, the medium and the detector. This anomalous redshift was first theoretically predicted by Santilli in 1992 [37], then experimentally confirmed also by Santilli in 2009 [38], independently confirmed via new measurements done by G. West et al [39], and known as Santilli IsoRedShift, where the prefix "Iso" indicates the use of the novel Iso-mathematics needed for quantitative treatments of propagation within physical media. When these measurements achieved on Earth's atmosphere are reported to the inhomogeneous and anisotropic medium in the interior of galaxies, Santilli IsoRedShift allows a quantitative representation of the anomalous redshift reported for galactic stars without any need for the conjecture of dark matter because light exits the medium inside a galaxy IsoRedShifted in a way depending on the travel within said medium, along the direction of stars to Earth. Additional independent confirmation, such as that via the demise of supersymmetries by recent experiments at CERN are contemplated for study at a future time.

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