The Structuring Force of Galaxies

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Abstract The assumption that the mass distribution of spiral galaxies is rational was suggested 11 years ago. The rationality means that on any spiral galaxy disk plane there exists a special net of orthogonal curves. The ratio of mass density at one side of a curve (from the net) to the one at the other side is constant along the curve. Such curve is called a proportion curve. Such net of curves is called an orthogonal net of proportion curves. I also suggested that arms and rings are the disturbance to the rational structure. To achieve the minimal disturbance, the disturbing waves trace the orthogonal or non-orthogonal proportion curves. I proved 6 years ago that exponential disks and dual-handle structures are rational. Recently, I have also found out that rational structure satisfies a cubic algebraic equation. Based on these results, this paper ultimately demonstrates visually how the orthogonal net of proportion curves go if the superposition of a disk and several dual-handle structures is still rational. That is, based on the natural root of the algebraic equation, the rate of variance along the 'radial' direction of the logarithmic mass distribution is obtained. Its image is called the 'basket graph'. The mystery of galaxy structure may possibly be resolved based on further study of the 'basket graphs'.

keywords: Rational Structure, Basket Graph, Spiral Galaxy

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1 The origin of Natural Structure

I proposed the idea that galaxy structure is rational. Fortunately, this paper serves the final episode of the full story, and gives a complete procedure for galaxy image analysis. The procedure provided is basically visual as galaxies show their majesty via visual images. Therefore, the general public can take action in the testification of galaxy rational origin. I believe that galaxy mystery can be resolved in the nearing future.

Why the study on galaxy structure is very important? The letter from Dr. Kamal Kant Dwivedi, the Adviser & Head of NCSTC, provides a good answer: "This has reference to your letter addressed to Hon'ble Prime Minister of India regarding your book 'Cosmic Origin of Dust and Humanity'. We have gone through the book and it emerged that the book emphasizes on finding the solutions for today's multifaceted problems and global crises by way of spreading the scientific knowledge of cosmic origin of dust and humanity in order to minimize the risk of sufferings driven by unquenched curiosities and mysterious feelings amongst people at large."

Humans live in the inter-related and complex natural environment. Humans led by their complicated emotion, have made many unnatural and complicated products. The world of artificial materials is so complicated that modern humans have almost forgot that they live in a natural world. Humans have done unprecedented destruction to the natural environment, and are not fully aware of its dangers. Although modern means of observing the universe is unprecedentedly powerful, modern humans have lost the religious respect for the nature whereas ancient humans did not.

The root cause of all the problems is that scientists have perfect understanding of only the electromagnetic and nuclear forces. However, these forces are not the structuring force of the natural world. Scientists have proved that an independent system of materials interacted by internal electromagnetic and nuclear forces tends to be uniformly distributed at macroscopic scale. This is the principle of entropy increase. The natural structure, however, is uneven yet orderly. This means that human beings have not found the scientific truth of natural structure origin.

Since humans can recognize only the impact of electromagnetic and nuclear forces in the microscopic world and the world of biological sphere, they should look up over the sky and observe the macroscopic world at larger scales. The example of relatively independent material systems at larger scale must be galaxies. In such large-scale system as galaxies, the electromagnetic and nuclear forces have no impact on the structure formation. Therefore, the understanding of galaxy formation is the critical step towards the understanding of natural world origin.

2 Introduction to Galaxy Structure

All galaxies demonstrate the structure of uneven material distribution. The density distribution of a relatively independent galaxy is always simple and orderly. Thus, uncovering the fundamental law on galaxy mass distribution is the basic step toward the understanding of galaxies.

The galaxy humans live in is called Milky Way. There are many galaxies in the universe. Relatively independent galaxies fall into two categories. One is the three dimensional-shaped elliptical galaxies, and the other is the flat-shaped spiral galaxies. It is surprising that elliptical galaxies present little materials other than stars. Therefore, the chance of life residing in elliptical galaxies is almost zero. We humans live in a spiral galaxy. The main structure of spiral galaxies is an axially symmetric disk with the stellar density decreasing exponentially along radial direction. It is the so-called exponential disk. Different from elliptical galaxies, spiral galaxies are subject to wavelike perturbation. The perturbation brings about arm structure of spiral shape. This is why they are named the spirals. In fact, the exponential disk of spiral galaxies can coexist with bar-shaped structure. There are two types of spiral galaxies. A barred galaxy has additional bar structure. Its body is a combination of exponential disk and bar structure. A spiral galaxy without bar structure (i.e., its body is simply the exponential disk) is called a normal spiral galaxy.

On the internet are many images of galaxies. We should be careful with color images. Color is essentially the different frequencies or wavelengths of light. In fact, the shape of an object or its image is the distribution of light arriving at your eyes from the surface of the object. That is, it is the distribution of light frequency and density varying with the surface of the object. Light of longer wavelength that appears reddish has strong penetrating ability.

In other words, reddish light refuses to be absorbed by dust or gas. Elliptical galaxies are very clean, with little observation of gas and dust. Therefore, it does not matter to catch which color for you to take the images of elliptical galaxies. Images of the same elliptical galaxy of different colors are very similar and smooth. They are the good demonstration of star distribution in the galaxy. But elliptical galaxies are three-dimensional while their images are two-dimensional. The image of an elliptical galaxy is the cumulative density of stars in the observing directions.

Spiral galaxies are just the opposite. They have a large amount of gas and dust. Although their structures are two-dimensional, they have a certain degree of thickness. Therefore, if we take images of spiral galaxies at the shorter wavelength (i.e., bluish light) then the light from the stars that are behind gas and dust are basically absorbed by the gas and dust. As a result, the image is more or less the distribution of gas and dust. Because the distribution of gas and dust is not smooth, the image looks rough. Internet images of spiral galaxies are usually short-wavelength ones, therefore, people are daunted by the mysterious look of gas and dust. Therefore, to get an image of spiral galaxy which is mainly stellar density distribution, we take light of longer wavelength from the galaxy, e.g., infrared wavelength. The resulting image is reddish. Although gas and dust have charming and bright colors, they have negligible mass.

This paper studies spiral galaxies only. Because spiral galaxies are flat shaped, we use the function of two variables

$$\rho(x, y) \tag{1}$$

to represent the stellar density distribution of spiral galaxies. Modern galaxy images are generally digital ones. Thus, a long-wavelength image of face-on spiral galaxy is, in essence, an array of positive numbers proportional to the stellar density: $\rho(i, j)$. The size of the array is dependent on the resolution of the image. We use the array to draw galaxy image (with the image brightness at each point being proportional to the corresponding value of the array).

3 The Structuring Force of Galaxies

3.1 The Definition of Rational Structure and the Components of Barred Spiral Galaxies

Since the ancient times, humans have not known what density distribution an independent natural material system should take. Scientists who study a flat material distribution generally consider its level curves, i.e., the contours of constant density. This resembles the situation that ancient mathematicians could not study mathematics beyond Algebra. Since Newton and Leibniz discovered Calculus in the seventeenth century, mathematics has been advanced revolutionarily. Back to the case of spiral galaxies, I want to study the change in the stellar density. Therefore I consider not the contours of constant density, but the variance rate of the density. Starting at any point on a plane are infinite directions along each of which we can calculate the variance rate of the density. The law of galaxy structure must be some property of invariance governing the rate of variance. I suggested a simple property of invariance. Among the infinite directions starting at a point are there two special ones which are mutually perpendicular. I consider only the variance rates along the two special directions. At any point on the plane are there two such special directions, and I always consider the variance rates along the two special directions. In fact, I am not interested in the variance rate of the density $\rho(x, y)$ but the variance rate of the logarithmic density,

$$f(x, y) = \ln \rho(x, y). \tag{2}$$

Therefore, considering the variance rate of the function $f(x, y)$, we get two functions, $u(x, y)$ and $v(x, y)$, which record the variance rates along the two special directions. Because these directions can connect into curves on the plane, the two special directions connect into two sets of parallel curves which are mutually perpendicular, called an orthogonal net of curves. The property of invariance I suggested is that the two sets of curves are, respectively, the level curves of the two functions $u(x, y)$ and $v(x, y)$. That is, the variance rate of $f(x, y)$ along the normal direction of any curve (from the net) is constant along the curve. This is my concept of rational galaxy structure.

Definition of rational structure (see the paper [1]): The logarithmic density distribution $f(x, y)$ on a plane is not arbitrary. There exists a special net orthogonal curves on the plane. The variance rate of $f(x, y)$ along the normal direction of a curve (from the net) is constant along the curve. The curve is called a proportion curve. The net of curves is called an orthogonal net of proportion curves. This kind of density distribution $\rho(x, y)$ is called a rational structure.

The exponential disk of spiral galaxies is a rational structure. It has infinite net of orthogonal curves. One net is composed of the curves of polar coordinates, i.e., all the circles centered at the galaxy center and all the radial lines starting the same center. The variance rate along the normal direction of the circles is denoted by $u(x, y)$, called the radial variance rate of $f(x, y)$. The level curves of $u(x, y)$ is all the circles. The variance rate along the normal direction of the radial lines is denoted by $v(x, y)$, called the axial variance rate of $f(x, y)$. The level curves of $v(x, y)$ is all the radial lines. Because exponential disks are axisymmetric, the axial variance rate is identically zero. The other infinite nets of orthogonal curves of the exponential disk are all spirals. Because the logarithmic density of the disk is proportional to the value of the radius vector $\mathbf{r}$, it can be proved that these spirals are all equiangular ones. That is, the angle between the tangent direction of the spiral at a point and the polar radial line passing the point is constant along the spiral. Because the gradient value of the logarithmic disk density is constant throughout, the variance rate along the normal direction of equiangular spiral is constant too. Equiangular spirals are also known as golden spirals or logarithmic spirals. Coincidentally, astronomical observations show that the arms of any normal spiral galaxies (i.e, the body structure is the exponential disk itself) are all equiangular spirals (see the third evidence (coincidence) of rational galaxy structure in [1]).

My research indicates that the bar of any barred spiral galaxy is a compound structure of two or three dual-handle structures. Each dual-handle structure is a rational structure. The lower left corner of Figure 1 is the mass density distribution of a dual-handle structure. In fact, it is one of the two dual-handles used to visually simulate the bar of galaxy NGC 3275. The orthogonal net of proportion curves of dual-handle structure is composed of all confocal ellipses and hyperbolas. The distance between the two foci is $2b_1$, known as the length of the dual-handles. Among the two variance rates along the two special directions, the one whose

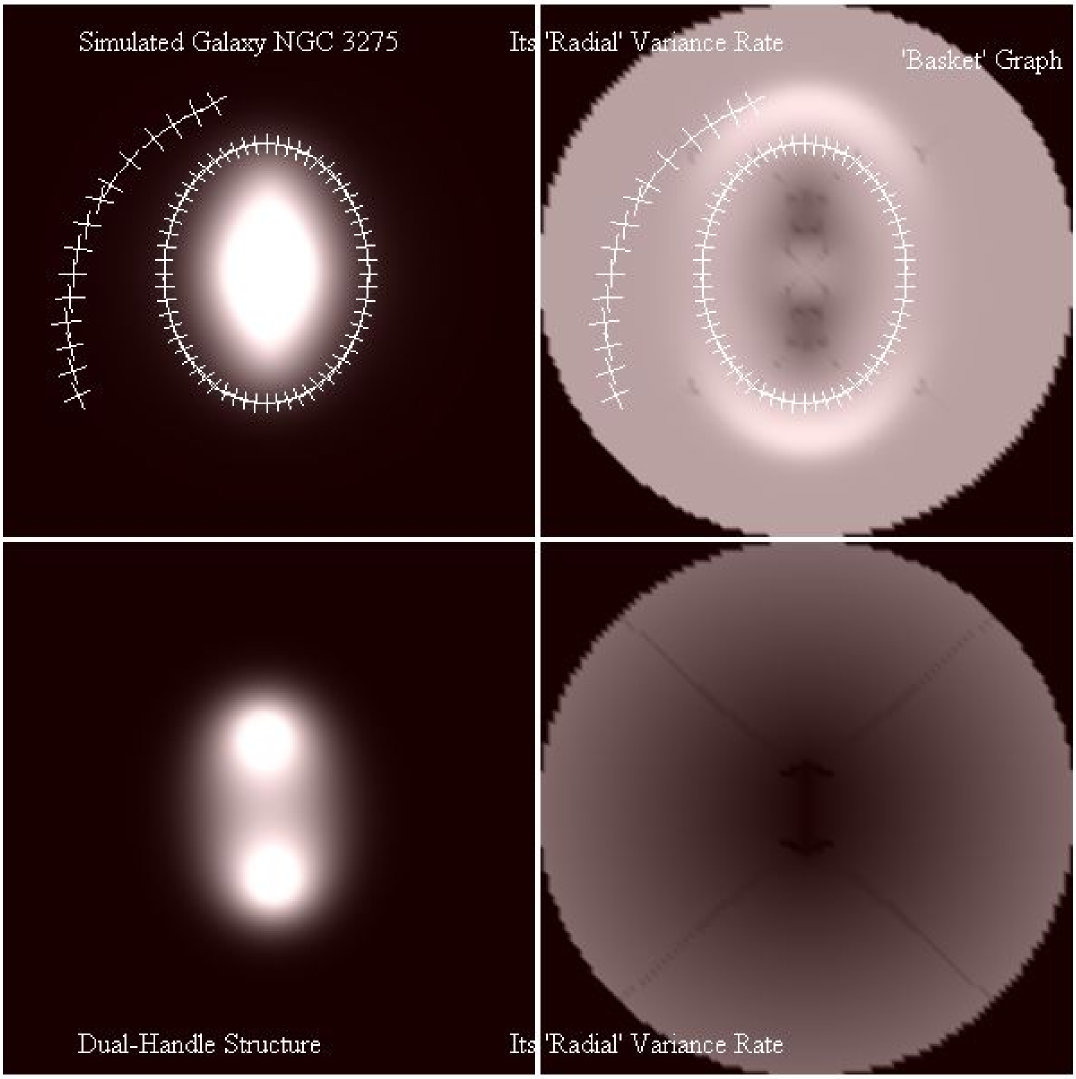

Figure 1: The upper left is the simulated barred spiral galaxy NGC 3275 with an exponential disk and two dual-handle structures. It is an image of density $\rho(x, y)$. The 'radial' variance rate, $u(x, y)$, of its logarithmic density is displayed in the upper right corner, called the 'basket graph'. The 'crosses' on the graphs show the real position of galaxy arms and rings (see the images in [2]). The lower left corner is the simulated shorter dual-handle structure, an image of density $\rho_1(x, y)$. The 'radial' variance rate of its logarithmic density is displayed in the lower right corner.

level curves are all the confocal ellipses is also called the 'radial' variance rate, denoted by $u(x, y)$, and the one whose level curves are all the confocal hyperbolas is also called 'axial' variance rate, denoted by $v(x, y)$. In fact, the normal direction of the ellipses do not generally point to the galaxy center but point to the galaxy bar. For visual purpose, I draw the image of the function $u(x, y)$, with the image brightness at each point corresponding to the value of $u(x, y)$. The level curves of the brightness must be all confocal ellipses. However, we see that the image at the lower right corner of Figure 1 is not smooth, which means that the function $u(x, y)$ is not smooth. It is because I used a more complicated method to calculate the function. The calculation presents large error near the two foci and the central line of the dual handles. The following paragraph explains this method and the origin of its error.

I have found the equation the slope of the orthogonal curves of any rational structure must satisfy. Surprisingly, it is a cubic algebraic equation, called the instinct equation (see [2]). The coefficients of the instinct equation are determined by the partial derivatives to the logarithmic density. The unknown of the equation is not directly the slope of the orthogonal curves. It is the 'doubled' slope. That is, the unknown is the tangent value of the doubled polar angle of the tangential line of the curves, i.e. $\tan 2\alpha$. In general, a cubic algebraic equation has three roots and the rational structure would have three orthogonal nets of proportion curves. However, the paper [3] demonstrated that only one of the three possible roots can give an orthogonal net of proportion curves. This root is called the nature's selection of algebraic equation roots. Because the formulas of the coefficients are highly symmetric, the coefficients are all zero for axi-symmetric rational structures. Because of this, there exist infinite nets of proportion curves on normal spiral galaxy disks. However, the coefficients of instinct equation for dual-handle structure are not all zero. There exists only one orthogonal net of proportion curves, namely the confocal ellipses and hyperbolas. However, I want to temporarily forget the ellipses and hyperbolas, and instead, seek the curves by solving the instinct equation. Dual-handle structure has the known logarithmic density $f(x, y)$ which is given by the formula (17) in [1]. To get the coefficients of the instinct equation, we calculate the partial derivatives of $f(x, y)$ using the formula (19) to (22) in [2]. Then we take the nature's selection of the roots which gives the slope of orthogonal proportion curves. The graph on the right in Figure 2 demonstrates many small lines which correspond to the calculated slope. At the same time we calculate the variance rate of $f(x, y)$ along the normal direction to the lines and the result is called the 'radial' variance rate denoted by $u(x, y)$. The lower right corner of Figure 1 is the demonstration of function $u(x, y)$ with the image brightness corresponding to the value of the function. We see that the image is not smooth. This is because there exist the points, i.e., the two foci, near where the orthogonal proportion curves are very crowded. Therefore, f (x, y) has no partial derivatives of the orders higher than two at the two points. In the vicinity of these points, the partial derivatives exist but their values tend to infinity. Because the computer can not accurately handle large values, the resulting image is not smooth. Fortunately the instinct equation is homogeneous about its coefficients and the formulas of the coefficients are highly symmetric. Therefore, we can eliminate the common denominators which tend to zero, and have computers always handling normal values. The denominators generally contain the following term (see the formula (16) in [1]),

$$(r^2 - b_1^2)^2 + 4b_1^2 x^2 \tag{3}$$

where r is the polar radius. The procedure to eliminating the singular denominator is left for future study. Away from the singular area, the computer's calculation is accurate, and the level curves of the function $u(x, y)$ are indeed confocal ellipse. Similarly, the logarithmic density of the exponential disk has a singular point, i.e., the center point, at which there is no partial derivatives of the logarithmic density though the structure is continuous.

3.2 The Variance Rate of the Whole Barred Spiral Galaxy and its 'Basket Graph'

The following introduction of 'basket graphs' for barred spiral galaxies is the main result of the paper. Since the body structure of any normal spiral galaxy is the exponential disk itself, there is no need for further study on normal spirals in this paper. Without regard to the central bulge, barred spiral galaxies are the superposition of exponential disks and bars. That is, their body structure is a compound one of rational structures. Is the compound structure which consists of an exponential disk and several dual-handle structures still rational? In [2], I proved the cubic algebraic equation (instinct equation) which a rational structure must satisfy. Now I find out that the steps of the proof are completely reversible. That is, given a smooth function $f(x, y)$ with at most a few singular points, if its instinct equation has a 'smooth root' (i.e., smoothly distributed slope lines, see the lines in Figure 2) then the logarithmic density $f(x, y)$ must correspond to a rational structure. Let us write it down as a mathematical theorem.

Theorem of rational structure: Given a logarithmic density $f(x, y)$ with at most a few singular points, if its instinct equation has a 'smooth root' (i.e., smoothly distributed slope lines) then the density must be a rational structure.

The proof is simple. Because the slope lines are smoothly distributed, the variance rates along the lines or their perpendicular directions, i.e. the functions $u(x, y)$ and $v(x, y)$, are smooth too. The level curves of the functions present two sets of parallel curves. Now we need prove that the curves are indeed the required orthogonal net of proportion curves. I find out that the steps of the proof for the instinct equation in [2] are completely reversible. Therefore, the level curves are indeed the orthogonal net of proportion curves and the corresponding density is indeed a rational structure.

My paper [3] demonstrates that the instinct equation for the model of barred spiral galaxies apparently has a 'smooth root'. The 'basket graphs' presented in the current paper which are generated by the root, are apparently smooth too. The confidence level is high to suggest that the compound structure that consists of an exponential disk and several dual-handle structures is still a rational one. Of course, a detailed analysis of the equation root for the model of barred galaxies can testify the suggestion.

Note that the non-smooth marks (lines or spots) in the Figures are due to the calculation errors of the computer, not the root. A non-smooth root must result from the non-smooth transition of the root from the area of positive discriminant of the instinct equation to the area of negative one. I sketched two bands of area in Figure 2 which correspond to the positive discriminant. We see that the 'basket graph' is smooth along the borders of the band areas.

The bar of a barred spiral galaxy is composed of two or three dual-handles. In this paper, we study the barred spiral galaxy NGC 3275 as an example. Through visual simulation, the

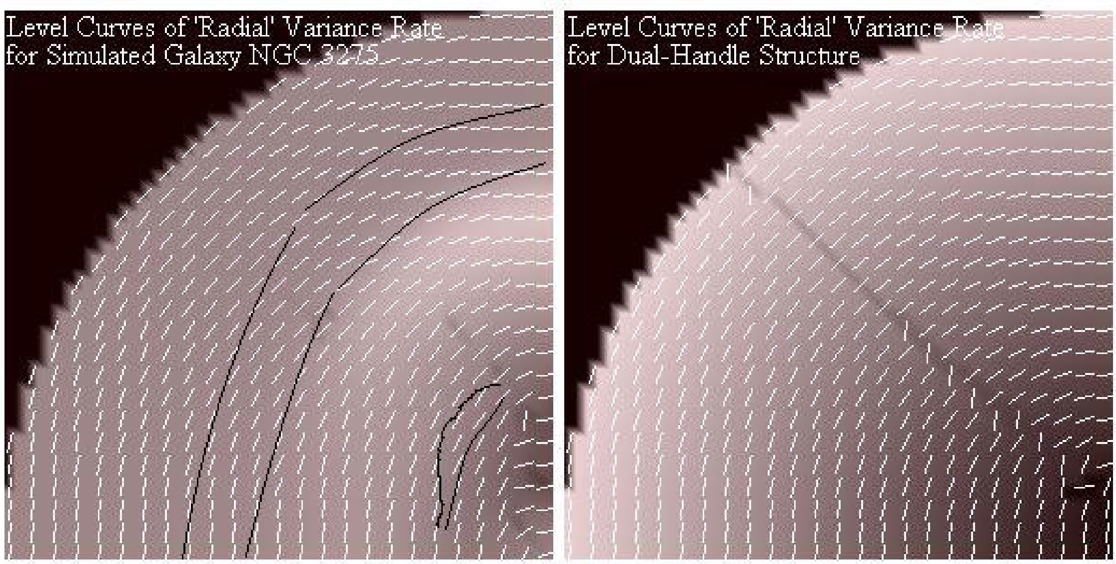

Figure 2: The graph on the left is the demonstration of the natural root of the instinct equation for the whole galaxy NGC 3275. The direction given by the natural root does follow the level curves of $u(x, y)$ which is the 'radial' variance rate of the whole logarithmic density. The graph on the right is the demonstration of the natural root of the instinct equation for the component dual-handle structure. The direction given by the natural root does follow the confocal ellipses which are the closed orthogonal proportion curves of dual-handle structure. See the text for the explanation of the sketches of two band areas.

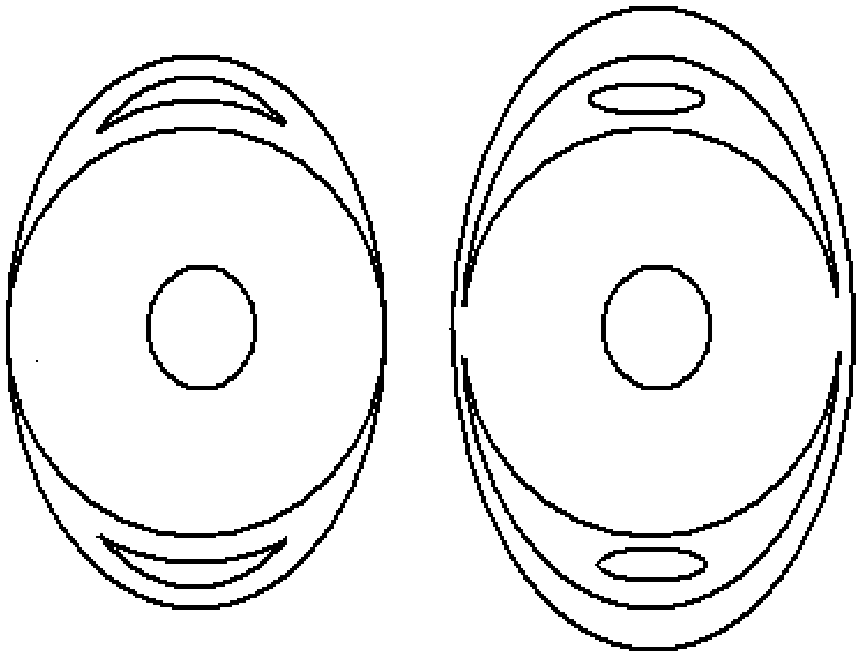

Figure 3: A sketch of the closed orthogonal proportion curves as revealed by the 'basket graphs' of barred galaxies. The graph on the left corresponds to the barred galaxies whose images do not have apparent dual handles while the graph on the right corresponds to the barred galaxies whose images do have apparent dual handles.

Table 1: The Fitting Values of Disk and Bar Parameters

galaxy	actual image size in arcsec	simulated side length	d_0	d_1	b_0	b_1	b_2	b_0	b_1	b_2
3275	110	22	1500	-1.6	134	1.76	-0.2	72	3.25	-0.095
4930	108	31	2200	-2.2	55	3.0	-0.08	56	5.73	-0.023
5921	185	7.4	5000	-10	144	0.31	-8.0	121	0.88	-6.0

bar is found to be the superposition of two dual-handle structures. The upper left corner of Figure 1 shows the simulated whole barred spiral galaxy (exponential disk plus galaxy bar). The fitting values of the parameters d_0, d_1 (exponential disk), b_0, b_1, b_2 (dual-handle structure) are presented in Table 1. The lower left corner of Figure 1 is the simulated shorter dual-handle structure. We denote the density of the structure by $\rho_1(x, y)$. The density of the longer dual-handle structure is denoted by $\rho_2(x, y)$ and the density of the simulated exponential disk is denoted by $\rho_0(x, y)$. Therefore, disregarding the central bulge, we have the visually simulated whole barred galaxy NGC 3275,

$$\rho(x, y) = \rho_0(x, y) + \rho_1(x, y) + \rho_2(x, y). \tag{4}$$

This is displayed in the upper-left corner of Figure 1. The gradient of the corresponding logarithmic density is

$$\nabla f(x, y) = \frac{\rho_0}{\rho}\nabla f_0(x, y) + \frac{\rho_1}{\rho}\nabla f_1(x, y) + \frac{\rho_2}{\rho}\nabla f_2(x, y) \tag{5}$$

where $f_0(x, y), f_1(x, y), f_2(x, y)$ are the logarithmic densities of the simulated exponential disk and dual-handle structures respectively. It indicates that the gradient of the compound logarithmic density is the weighted averaging of the gradients of the components' logarithmic densities. The weight is the percentage of the component's density over the whole density (not the whole logarithmic density, see the final formula on page 371 in [1]).

Since we do not know the orthogonal net of proportion curves for the whole barred spiral galaxy, we seek the curves by solving the instinct equation as described in the above Section. To get the coefficients of instinct equation, we calculate the partial derivatives of the simulated whole logarithmic density $f(x, y)$ by using the formula (5). Then we take the nature's selection of the roots which gives the slope of the orthogonal proportion curves. The graph on the left in Figure 2 demonstrates many small lines which correspond to the calculated slopes. At the same time we calculate the variance rate of $f(x, y)$ along the normal direction to the lines, and the result is called the 'radial' variance rate, denoted by u (x, y). The upper right corner of Figure 1, called the 'basket graph', is the demonstration of the function $u(x, y)$ whose image brightness corresponds to the value of $u(x, y)$. The level curves of $u(x, y)$ are expected to be the closed proportion curves which surround the galaxy bar. The small lines (given by the natural root) as shown on the left-hand graph in Figure 2 do follow the level curves of $u(x, y)$. This is the complete procedure of barred galaxy image analysis. Figure 3 is the sketch of the closed proportion curves indicated by the 'basket graph'. We see that, except the rim area of the 'basket' and the places near the four foci, the closed proportion curves are 'elliptical' shaped. The longer axes of the 'ellipses' are parallel to the galaxy bar. This result is very important because it is the basis of most rational galaxy evidences argued in [1].

The upper-right graph in Figure 1 (i.e, the 'basket graph') still presents the marks of four foci of the dual-handle structures. They are caused by the errors of computer calculation. Surprisingly, the brightest part of the graph, i.e., the rim of the 'basket', is located outside the four foci. In other words, the function $u(x, y)$ takes its peak value just outside of the foci. Figure 4 is the demonstration of the 'basket graphs' of the other barred galaxies: NGC 4930 and NGC5921.

Why is there the 'basket graph'? The answer is the following. In the area near galaxy center and the four foci, the density of the exponential disk, i.e. the weight factor in (5), is the greatest and makes the overwhelming contribution to the formula (5). However, the absolute value of the logarithmic densities of the dual-handle structures increase with radius to the order of three whereas the absolute value of the logarithmic density of exponential disk increases linearly. Therefore, the gradient values (i.e. the second factors in (5)) of the logarithmic densities of the dual-handle structures are the greatest and make the overwhelming contribution to the formula (5) at around the area of the 'basket' rim. However, far away from the galaxy center, the first factor in (5), i.e. the weight factor, make larger impact, and the density of the exponential disk is the greatest which makes the overwhelming contribution to the formula (5).

The fact that spiral galaxies can be fitted with rational structure is a marvelous result. But the most marvelous one is the revelation of how gas and dust originate. Since there is no elementary complex function whose corresponding rational structure is linear-shaped one like a spiral, galaxy arms and rings must be the disturbance to the rational structures. Images of spiral galaxies show that the greater the disturbance to the body structure, the more dusts and gases resulted, and the greater the events of star birth. Only dusts and gases contain significant amount of elements that are heavier than hydrogen and helium which the living structures need. Elliptical galaxies do not show much evidence of life, and the disturbance to their bodies is hard to be observed. For example, Elliptical galaxies present no significant arms.

The disturbing waves try to achieve the minimal disturbance and, as a result, follow the orthogonal or non-orthogonal proportion curves. Note that spiral arms are usually broken-shaped (not connecting end to end), composed of segments which follow orthogonal or non-orthogonal proportion curves [2]. Galaxy rings follow the closed orthogonal proportion curves, i.e., the level curves of $u(x, y)$. Spiral arms trace non-orthogonal proportion curves and cut through the orthogonal curves proportionally. Figures 1 and 4 show the real position of arms and rings on the graphs (see [2]). Note that these examples demonstrate that all rings are located inside the 'baskets'. These rings can be called the inner rings. There are other types of rings for barred galaxies: outer rings and nuclear rings [5]. The nuclear rings must be located in the central convex balls of the 'basket graphs', and they are approximately circular. Galaxy rings can not coincide with the bright 'basket rims'. This is because the brightness of the rims is usually uneven. As shown in Figure 3, the orthogonal curves around the rims are in fact not the closed ones surrounding the bars. Figures 1 and 4 show that the rings are located immediately off the rims. However, arms can cross through the basket rims because the 'non-radial' variance rates of $f(x, y)$ are usually small. For example, the absolute value of the 'axial' variance rate $v(x, y)$ for the galaxy NGC 3275 is generally so

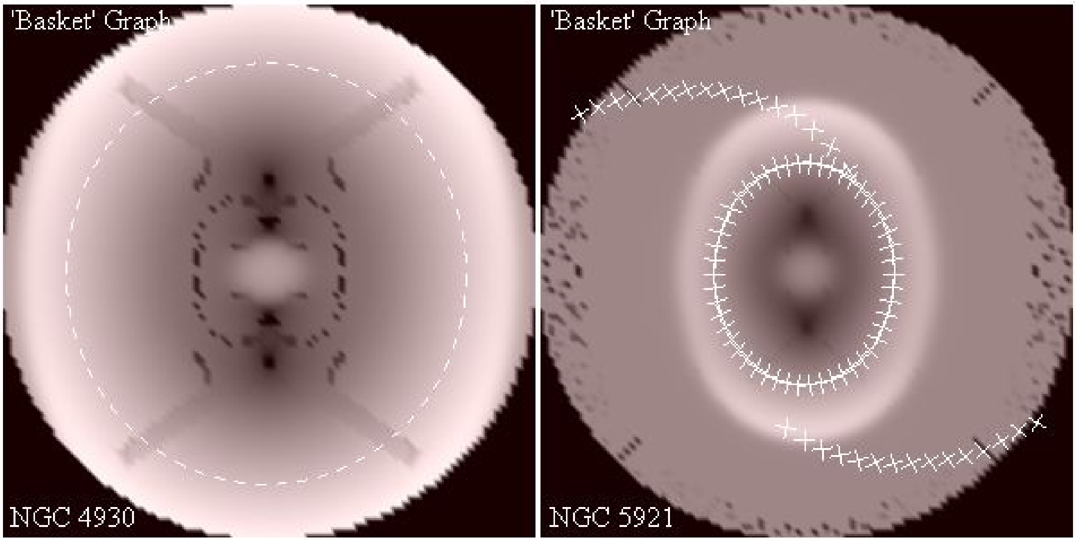

Figure 4: The 'basket graphs' of the galaxies, NGC 4930 and NGC 5921. The dotted lines and the 'crosses' on the graphs show the real positions of galaxy arms and rings (see the images in [2]).

small that it is buried in the numerical errors of ordinary computer calculation.

3.3 The Evidences of Rational Galaxy Structure

Dual-handle structures which are the components of barred galaxies, are the simple analytical solution of rational structure. The twelve evidences (coincidences given in [1]) of spiral galaxies as the compound rational structure are mostly based on the results of the component rational structure, i.e., the dual-handle structure. Because galaxy disks take their maximum values at around the galaxy center and dual handle structures take the values away from the center, the formula (5) indicates that the evidences are still true. The above explanation of 'basket graph' origin further justifies these evidences. Now let us review the twelve evidences.

(1) The component structure of any galaxy (except the arm) is either axi-symmetric or bilaterally symmetric. Theoretically, the examples of rational structure are very few, which are generally axi-symmetric. The only example found so far which is not axi-symmetric is the dual-handle structure, and it is bilaterally symmetric. (2) Gas and dust are closely related to arms and rings while arms and rings are the disturbance to rational structure. This indicates that gas and dust result from the disturbance to rational structure, which is a very promising explanation to gas and dust origin. (3) In normal spiral galaxies, exponential disks and equiangular arms are linked through the concept of rational structure. (4) Among all rational structures determined by the orthogonal curves expressed by elementary complex functions, there is only one structure which is not axi-symmetric: the dual-handle structure. Coincidentally, there are only two types of spiral galaxies: normal and barred. In addition, some barred spiral galaxies do present apparently the dual-handle structure. (5) In some galaxies (e.g. NGC1365) there exist two bars which are not aligned. This can be explained simply: the corresponding dual-handle structures are not aligned. (6) We know that the disk density of spiral galaxies decreases outwards exponentially, which is the numerical result observed over 80 years since the discovery of galaxies in the universe. Spiral galaxy disks are thus called exponential disks. We add the dual-handle structure to the exponential disk for them to be the model of barred spiral galaxies. If the density of dual-handle structure were comparable to or stronger than the exponential disk in the far distances from the galaxy center then our model would fail. That would suggest that the main structure of spiral galaxies were not the exponential disk, a result inconsistent with astronomical observation. The mathematical result is that the density distribution of dual-handle structure decreases outwards cubic-exponentially. That means the bar structure is so weak in the outer areas of spiral galaxies that it is ignored. (7) Astronomical observations show that arms of barred spiral galaxies surround the middle lines of their bars, and they are not equiangular. Generally there are two arms making approximately elliptical shapes with the long axes being parallel to the bar middle lines. The 'basket graphs' confirm the result. (8) Normal spiral galaxies do not have elliptical ring while barred spiral galaxies may have elliptical rings. These are confirmed by the models of both normal and barred spiral galaxies. (9) The image sample of nine barred galaxies can visually be simulated with dual-handle structures. (10) Elliptical galaxies can also be simulated with three-dimensional rational structure (see [4]). (11) The components of spiral galaxies, i.e. the exponential disk and dual-handle structure, all have the orthogonal proportion curves expressed by the complex exponential function. Elliptical galaxies have the orthogonal proportion curves expressed by the complex reciprocal function.

These results are in line with the principle of truth simplicity. (12) 'Basket graphs' show that barred spiral galaxies may have nuclear rings and arms which are located in the central area of 'baskets', which is confirmed in galaxy image analysis.

We can investigate 'basket graphs' deeply and find further evidences of rational galaxy structure. We take a preliminary overall look at 'basket graphs'. Outside the 'baskets', the orthogonal proportion curves return to the ones of exponential disks, and the disks have infinite nets of proportion curves which are generally equiangular. Barred galaxy images do show that the arms are much richer outside of the bars. The area near galaxy bars is cleaner and has less gas and dust. Arms can cross the 'baskets' but their curves can not be parallel to the 'basket' rims for the same reason for galaxy rings. Galaxy images show that some arms originate from around the endpoints of bars and the arms make a sharp turn near the endpoints. The turn, near the endpoints, is so sharp that the arms are approximately perpendicular to the 'basket' rims.

4 The Promise of Future Rational Galaxy Study

"What exactly is a galaxy? Surprising as it may sound, astronomers don't have an answer to this fundamental question." These are the opening words of a piece of January news (2011) in Science magazine written by Jon Cartwright. The news introduces a scientific paper [6] and an online survey launched by the paper's authors. Astronomers have long known that galaxy structure is very simple [7] but the two-body theories of gravity established by Newton and Einstein can not explain it. According to these theories, galaxy formation and evolution should be governed by six independent parameters. However, the astronomical observation shows that only one parameter is independent. My simple model of galaxy structure is based on galaxy images and the simple concept of rationality. Real galaxy structure may be even simpler. For example, the parameter in the third column of Table 1 is the simulated side-length of galaxy images, and the simulated values of other parameters are dependent on it. Galaxy structure may be so simple that it is scale invariant. That is, the simulated side-length may actually be arbitrary. This suggestion is left for future testification.

If galaxy structure is meaningful then it is unlikely to find a simple and consistent meaning that is different from the meaning of rationality explained in my papers. It is unlikely that galaxy structure has no meaning.

'Basket graph' will play an essential role in future study on barred galaxies. We humans live in a barred galaxy. What does the 'basket graph' of Milky Way look like? Do human beings live inside or outside the 'basket'? The mass distribution of galaxies, i.e., the stellar distribution, is represented by the long-wavelength galaxy images. However, life phenomena are more involved in the distribution of gas and dust. Therefore, the study of the correlation between the 'basket' structure and the corresponding galaxy structure shown on short-wavelength images may reveal some surprising results.

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