Sakaji-Licata Arms: NGC 3275

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Abstract It may be true that mankind's hope is the identification of the living meaning of natural structures. However, scientists including physicists, chemists, and biologists have not found any evidence of the meaning. In the natural world, there exists one kind of structure which is beyond the scope of human laboratorial experiment. It is the structure of galaxies. Spiral galaxies are flat disk-shaped. There are two types of spiral galaxies. The spiral galaxies with some bar-shaped pattern are called barred spirals, and the ones without the pattern are called ordinary spirals. Longer-wavelength galaxy images (infrared, for example) show that ordinary spiral galaxies are basically an axi-symmetric disk that is called exponential disk. For a planar distribution of matter, Jin He and Bo He defined Darwin curves on the plane as such that the ratio of the matter densities at both sides of the curve is constant along the curve. Therefore, the arms of ordinary spiral galaxies are Darwin curves. Now an important question facing humans is that: Are the arms of barred spiral galaxies the Darwin curves too? Fortunately, Dr. Jin He made a piece of Galaxy Anatomy Graphic Software (www.galaxyanatomy.com). With the software, not only can people simulate the stellar density distribution of barred spiral galaxies but also can draw the Darwin curves of the simulated galaxy structure. Therefore, if Dr. Jin He's idea is true then people all over the world will witness the evidence that the arms of barred spiral galaxies are identical to the corresponding Darwin curves. This paper shows partial evidence that the arms of galaxy NGC 3275 follow Darwin curves. Note: Ammar Sakaji and Ignazio Licata are the founder or the editor-in-chief of the Electronic Journal of Theoretical Physics. Over fifty journals of astronomy and physics had rejected Dr. Jin He's core article on galaxy structure before 2010. It is Sakaji and Licata's journal that accepted the article.

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1 The Mystery of Galaxy Arms

Spiral galaxies are thin, flat disks, composed of stars, dust and gas, but mainly of stars. Independent spiral galaxies belong to two types. A spiral galaxy with a bar is called a barred spiral, and a spiral galaxy without a bar is called an ordinary spiral. If a galaxy image is taken with longer wavelength radiation, such as infrared one, the light

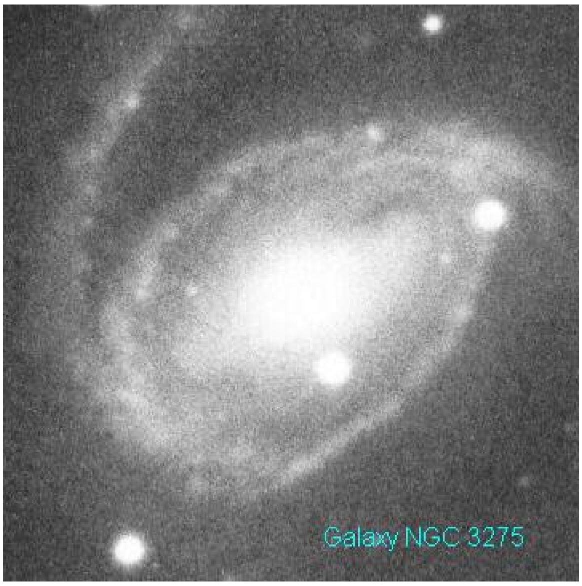

Figure 1: Image of galaxy NGC 3275 with optical light (shorter-wavelength radiation).

distribution is comparable to the stellar distribution of the galaxy. This can be described by a function of x and y on the galaxy disk plane,

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

Because it represents the stellar density at the point (x, y), the value of $\rho(x, y)$ is always positive.

Some people are not interested in a mathematical function. Instead, they may be interested in its graphic demonstration. Fortunately, a function on xy plane can be projected as a surface in 3-dimensional space. At the origin $(x = 0, y = 0)$ we set up a third axis ($z-$axis) which is perpendicular to the plane. The vertical distance from the surface to the plane is the value $z = \rho(x, y)$. If the value is positive, the corresponding point on the surface is above the xy plane, otherwise below the plane. For a spiral galaxy, the vertical distance from the projected surface to the xy plane is the stellar density. Since stellar density is always positive, the surface (graph) is above the xy plane. Because the stellar density at galaxy center is the greatest, the corresponding distance is the longest, and the graph looks like a mountain with the peak corresponding to the galaxy center. From spiral galaxy images we see many spiral arms. The arms spiral outwards from the galaxy center or the galaxy bar. Therefore, galaxy arms can be projected as a highway that spirals down the mountain around the peak or around the ridge (in the case of galaxy bar). How the highways spiral down the mountain is of great scientific mystery. The French scientist Henri Poincaré once spoke of the mystery:

"One fact that strikes everyone is the spiral shape of some nebulae; it is encountered much too often for us to believe that it is due to chance. It is easy to understand how incomplete any theory of cosmogony which ignores this fact must be. None of the theories accounts for it satisfactorily, and the explanation I myself once gave, in a kind of toy theory, is no better than the others. Consequently, we come up against a big question mark."

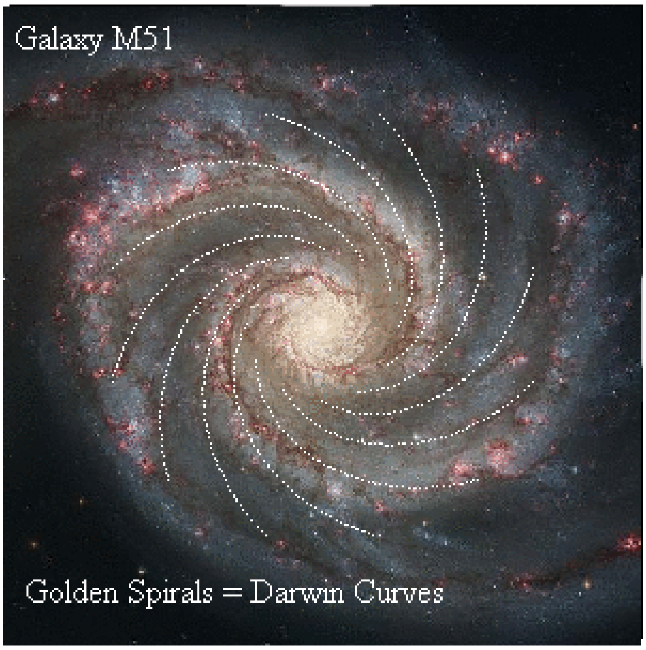

Figure 2: Image of ordinary spiral galaxy M51 with optical light. Its arms follow the Darwin curves of the rational structure (the exponential disk).

2 Spirals down the Mountain at a Constant Slope

As common people, we may build the highway with a constant slope. However, Dr. Jin He suggested in Fall 2000 that the arms choose the way at constant ratio of mountain heights on either sides of the way (i.e., constant ratio of stellar densities). Nevertheless, Dr. Jin He's suggestion does connect to constant slope if we consider logarithmic mountain height (i.e., logarithmic stellar density)

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

instead of the direct mountain height. This is because the ratio of stellar density is equivalent to the variance rate of its logarithmic density. If we project the logarithmic density as surface then the variance rate is equivalent to the slope of the surface. But the slope is not in the tangent direction to the highway. Instead the slope is in the perpendicular direction to the highway. In summary, if we project the logarithmic density distribution as a surface then Dr. Jin He suggests that galaxy arms go such a way on the surface that the slope in its perpendicular direction is constant along the way. Such ways are called Darwin curves [1]. This means that, in terms of density distribution, a galaxy arm is a Darwin curve that the variance rate of the logarithmic stellar density in the perpendicular direction to the curve is constant along the curve. Dr. Jin He has studied this idea since Fall 2000 (see references [2–8]). By the end of 2012, he has finished the second version of Galaxy Anatomy graphic software [9]. With the software, people can simulate the stellar distribution of any barred galaxy, and then find its Darwin curves. Comparing the curves with the real galaxy arms can testify Dr. Jin He's idea.

It is straightforward to prove that Dr. Jin He's idea is true for all ordinary spiral galaxies. Astronomers found out that the stellar density distribution of ordinary spiral galaxies is basically an axi-symmetric disk described by the formula,

$$\rho(x, y) = d_0 \exp(d_1 r) \tag{3}$$

where d_0 and d_1 are constants. It is called the exponential disk. Its corresponding logarithmic stellar distribution is,

$$\log \rho(x, y) = \log d_0 + d_1 r \tag{4}$$

This is a linear function of the radial coordinate r. Its variance rate in radial direction is the constant d_1 on the whole galaxy disk. If we project the function (4) as a surface then the variance rate is the slope of the mountain surface. Because function (4) is linear, the corresponding surface is a cone. Therefore, the above radial variance rate d_1 is the maximum slope of the cone. That means the slope in the perpendicular direction to the horizontal circles on the cone is constant and maximum. However, if we go down a spiral curve on the cone, the slope in the perpendicular direction to the curve is less than the maximum.

Now, the question is: What is the spiral curve on the cone with a constant perpendicular slope? We know that a curve on the cone which crosses a horizontal circle with an angle θ must have a slope

$$d_1 \cos\theta \tag{5}$$

If the curve crosses all horizontal circles with a constant angle θ then the product $d_1 \cos\theta$ is constant too. Therefore, the answer to the above question is that the spiral must cross all the horizontal circles with a constant angle. We call such a spiral a golden spiral. Its projection on the x-y plane is also called a golden spiral. Astronomers found out that the spiral arms of ordinary spiral galaxies are all golden spirals (see Figure 2). This proves that Dr. Jin He's idea is true for all ordinary spiral galaxies.

Since 2005 Dr. Jin He has focused on the study of his idea on barred spiral galaxies. Astronomers have found out that the main structure of barred spiral galaxies is also the exponential disk. Therefore, we subtract the fitted exponential disk from a barred spiral galaxy image. What is left over? Jin He discovered that the left-over resembles human breasts [7]. Jin He calls it double-breast structure. Barred spiral galaxies, however, have more than a pair of breasts. The bar of barred spiral galaxies is composed of two or three pairs of breasts which are usually aligned. The addition of the two or three pairs of breasts to the major structure of exponential disk becomes a bar-shaped pattern which crosses galaxy center (see Figure 3).

Therefore, the logarithmic stellar density of barred spiral galaxies is no longer a linear function of radial coordinate r, and golden spirals are no longer their Darwin curves. What are the Darwin curves for barred spiral galaxies? Do the real arms of barred spiral galaxies follow Darwin curves?

3 Darwin Curves of Barred Spiral Galaxies

Darwin Curves: If the variance rate in the perpendicular direction to the curve on a logarithmic stellar density distribution is constant along the curve then the curve is called a Darwin curve.

If we project the logarithmic stellar density of barred spiral galaxies as a surface then the definition of Darwin curves is that the slope in the perpendicular direction to the curve on the surface is constant along the curve. To find Darwin curves, we are beforehand given

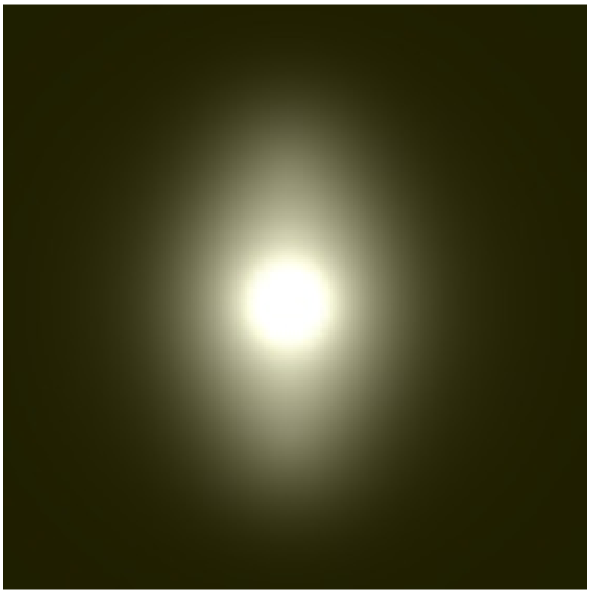

Figure 3: The simulated galaxy NGC 3275, i. e., the superimposed structure of double-breasts and exponential disk.

Table 1: Structure Simulation of Galaxy NGC3275

image length$''$	coordinate assignment	sky level	d_0	d_1	b_0	b_1	b_2	b_0	b_1	b_2
110	100	1005	2000	0.3	134	8	-0.002	72	14	-0.001

a constant value of slope. We have a given point on the surface and calculate the maximum slope at the point. If the maximum slope is greater than the given slope then there exist two curves crossing the point (i.e., two directions) whose slope at the point are the given one. Therefore, we can apply the integral method for ordinary differential equation to solve our question, i.e., to find Darwin curves crossing the given point for barred spiral galaxies.

4 Darwin Curves of Galaxy NGC 3275

Before we find the Darwin curves of a barred spiral galaxy, we simulate its stellar density distribution so that we have an analytic formula of the distribution that is ready for the calculation of its variance rate. Table 1 is the result of the simulation for galaxy NGC 3275 with Galaxy Anatomy graphic software. Figure 4 is a galaxy image corresponding to a square area on the sky. The area makes a perspective angle at the observer on Earth. The first column in Table 1 is the angle in the unit of arc second. The angle for the galaxy image is 110 arc seconds, i.e., 110$''$. It is impossible to measure the accurate size of a galaxy. Therefore, we assign an arbitrary value for the side length of the above square area. We chose the value to be 100 as shown in the second column of the Table. The third column is the sky level of the image. Sky level varies with different images which is the light coming from the local city or other sources when people take the images. All other columns are the simulated parameter values for the galaxy stellar density distribution

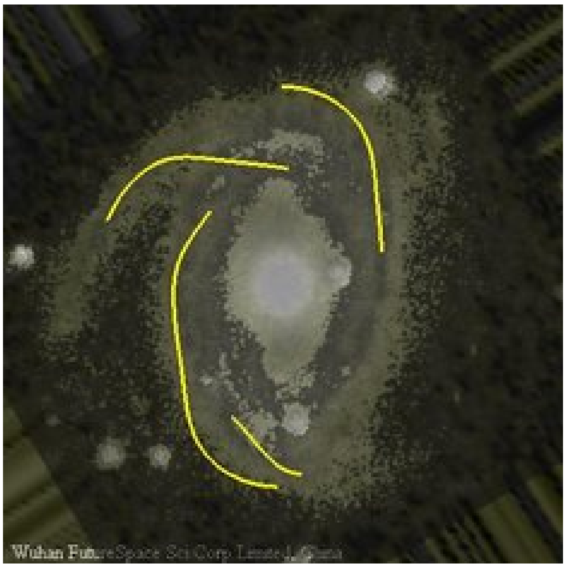

Figure 4: The yellow curves are the examples of Darwin curves calculated with Galaxy Anatomy graphic software.

with Galaxy Anatomy graphic software.

Armed with the analytic expression of galaxy structure, we can calculate Darwin curves as suggested in the above Section. The curves in Figure 4 are examples of the Darwin curves. The result shows some evidence that the arms of galaxy NGC 3275 follow Darwin curves.

5 Conclusion

Galaxy Anatomy graphic software (version 2) employs the Runge–Kutta method to calculate the Darwin curves of simulated galaxy structure. Figure 4 presents an example of galaxy NGC 3275. The Figure shows some evidence that the arms of galaxy NGC 3275 follow Darwin curves. If refined calculation and more examples of galaxy images support the result then we are certain that Dr. Jin He's idea on galaxy structure approaches the cosmic truth.

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