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Tadpole Galaxy (UGC 10214) Morphology May be Formed by the Combination of the ROTASE Mechanism and Galactic Merging

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The image of the Tadpole galaxy or Arp 188 or UGC 10214 is carefully studied in this paper, the alternative mechanism for the formation of the Tadpole galaxy is proposed based on the ROTASE model with the information extracted from the image. The Tadpole galaxy and the other two smaller galaxies formed a well isolated local galactic cluster with mutual gravitational interactions. The three galaxies are approaching each other in merging under the gravitational forces. The Tadpole galaxy was initially a normal galaxy with unequal X-matter emission, one side of X-matter emission was strong, but the other side of X-matter emission was weak or had no emission. The Tadpole galaxy initially had a fast motion to the pair of smaller galaxies and had relatively slow rotation, the straight-like arm was generated in this period. When the three galaxies are close enough, the rotation of the Tadpole galaxy increased significantly, and the weak side X-matter emission increased significantly also, so, both arms are strong and clearly visible. Two smaller galaxies are close enough to form a pair with the galactic bridge, and the pair penetrated the Tadpole galaxy through its second (short) arm, seriously distorted the second arm. The strong mutual gravitational tidal forces among the three galaxies pulled the central disc area of the Tadpole galaxy out of its disc plane, changed the Tadpole rotation axis, this caused the morphology of the Tadpole galaxy like a sandwich structure, in which, the short spiral arm is on top, the central bar disc is in the middle, and the other long arm is at the bottom. The galaxy has a right-handed spiral chirality. The local cluster of the three galaxies will merge very soon in the time scale of the universe evolution, the morphology of the cluster will continue to

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change, the long straight tail will be invisible after all hydrogens are depleted. The two smaller galaxies formed a tadpole galaxy with double clumps; therefore, due to the huge size difference between the two different types of tadpole galaxies and the unique morphology, the current Arp 188 can be viewed as a hybrid of one type of tadpole galaxy parasitic inside of another type of tadpole galaxy, or humorously, a woman bearing a baby of another race through a transplant.

Keywords: Tadpole galaxy; galactic cluster; galactic collision; galactic merge; ROTASE model; X-matter emission.

1. INTRODUCTION

The Tadpole galaxy, also known as UGC 10214 galaxy or Arp 188 or VV 29, is a very famous galaxy that has the spiral structure of a Tadpole head with a long and straight tail, its whole morphology is like the Tadpole from which the name came from. The unique morphology of the galaxy inspired great attention [1-3]. However, the mechanism for the formation of the Tadpole galaxy is still unclear. Rosado-Belza et al. [4] described that the galaxy has experienced a minor merger about several hundreds of Myrs ago, the encounter minor galaxy with much less mass has distorted the Tadpole disc and caused gas to be ejected in a long (~ 110kpc) tidal tail, which is similar to the classical weak galaxy-galaxy interaction described by Toomre et al. [5]. Trentham et al. [6] described that the material is flowing out of the galaxy towards apparently nothing, it is possible that material is being gravitationally pulled out of the galaxy by a dark companion, just like material is pulled out of one member in a more normal interacting system by another member. The NASA (National Aeronautics and Space Administration of the US) and European Space Agency websites describe this galaxy as a victim of a possible hit-and-run incident by a much smaller compact intruder galaxy which can be seen in the galactic disc area, the intruder is about to leave the scene. Both the main disc head and the long tail are vigorous new star-forming areas with very rich hydrogen gas, Jarrett et al. [7] studied in detail about the new star-forming activities in the disc head and the tail based on the ground-based optical data. However, if we inspect the image of the Tadpole galaxy carefully, an alternative description of the formation of the unique morphology of this galaxy may be drawn based on the information extracted from the image, such an alternative description will be provided in this paper.

2. DETAILED DESCRIPTION OF THE TADPOLE GALAXY AND THE POSSIBLE FORMATION MECHANISM

Fig. 1 is the original ACS (Advanced Camera for Surveys) full field image of the Tadpole galaxy UGC 10214, it has a long straight tail extended diagonally from upper left to lower right, the Tadpole head has well-formed spiral arm characteristics. The ACS was installed aboard NASA's Hubble Space Telescope). With careful inspection, it can be found that there are two bright spots located slightly above the center of the Tadpole galaxy, one of them should be the small, compacted intruder mentioned above, labeled as the Intruder 1, the other spot is also a small, compacted galaxy labeled as the Intruder 2 in the image. There are no visible objects in the vicinity of the end of the straight tail at the lower right corner except for the small spots of remote background galaxies.

In general, if two galaxies are close enough, the galactic material will be pulled out by the gravitational tidal force and form a bridge (indicated by the red arrows) between the two galaxies shown in Fig. 2 with examples of Arp 271 (made of galaxy 5426 and galaxy 5427) and Arp 282 (made of the galaxy NGC 169 and the galaxy IC 1559). The gravitational tidal force is not selective, any gravitational matter will be pulled toward the center of gravity. So, the long straight tail of the Tadpole galaxy cannot be the result of pulling by another visible galaxy. Trentham et al. [6] proposed that the long straight tail could be caused by the gravitational tidal force of a complete dark galaxy located at the end of the tail as a dark companion, such dark galaxy contains cold dark matter. However, the dark galaxy must be very massive and sizable (probably much larger than the Tadpole galaxy) to cause such long tail bridge. However, such proposed large, massive dark galaxy should have an optical blocking/scattering/blurry effect on the light from the remote background

galaxies, except for the case that the dark galaxy is completely transparent to those remote background light. An image with a large field of view of this galaxy clearly shows images of remote background galaxies at the end of the tail area without any scattering or blurry effect as shown in Fig. 3, the quality of those spots is the same as spots in other areas, each such spot is a far remote galaxy; so, the dark galaxy is not favorable in this case. If such a dark galaxy does exist in that area, it may have the gravitational lens effect.

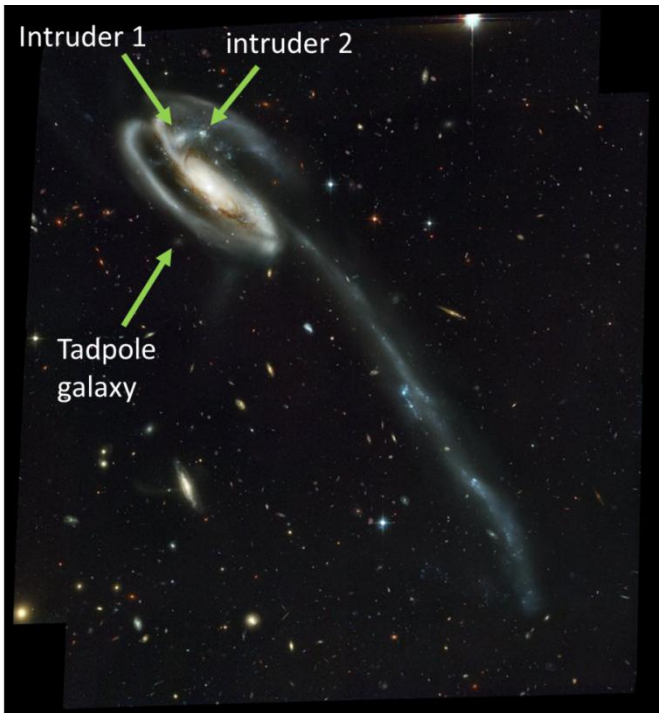

Fig. 1. The image of the Tadpole galaxy UGC 10214 with labeled 3 galaxies as a local galactic cluster. The image is credited to: NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M.Clampin (STScI), G. Hartig (STScI), the ACS Science Team, and ESA

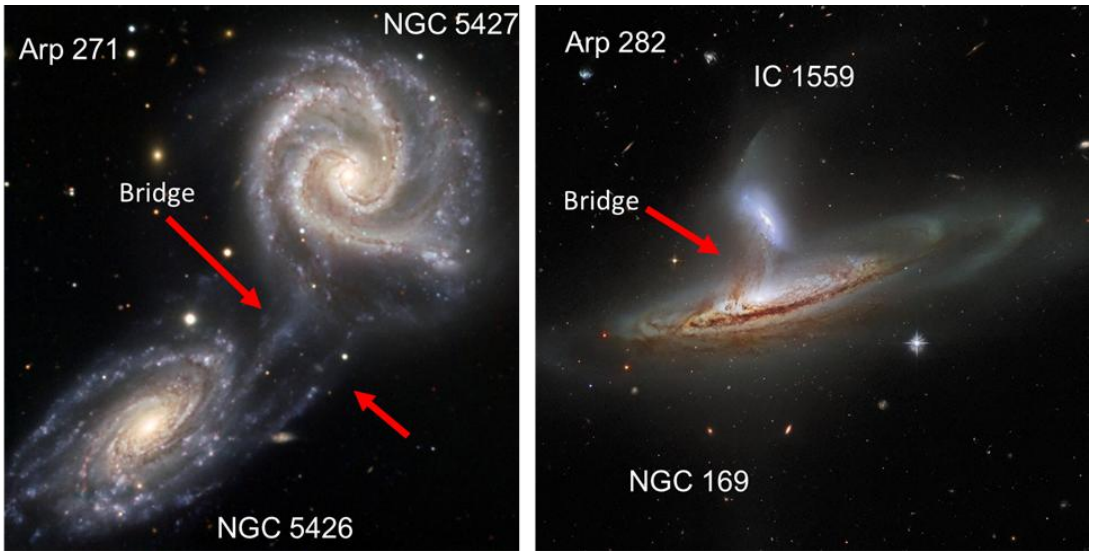

Fig. 2. Intergalactic bridges formed by two galaxies. Left is Arp 271, a pair of colliding galaxies NGC 5426 and NGC 5427; right is Arp282, a pair of colliding galaxies NGC 169 and IC 1559

Fig. 3. A color composite image in the g, r and i bands of UGC 10214 known as Tadpole Galaxy in the ELAIS-N1 region. Credit: NAOJ/HSC Project

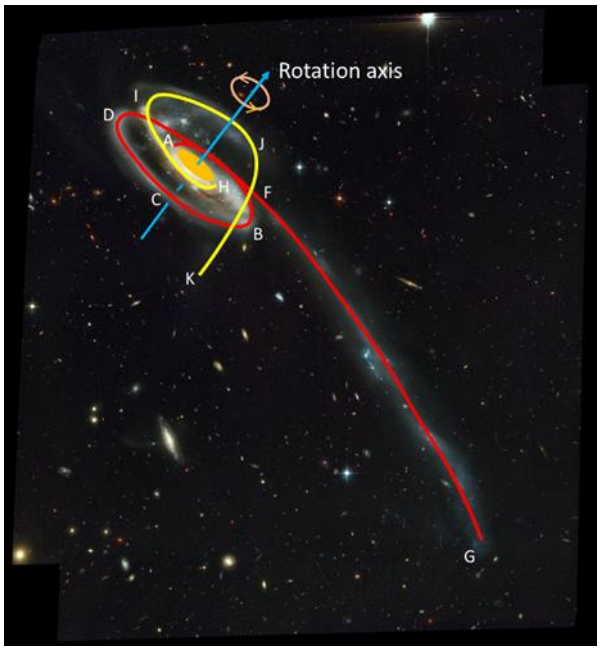

Fig. 4. The depicted spiral pattern of the Tadpole galaxy

The long straight tail can be smoothly traced all the way to the galactic center shown in Fig. 4 by the red line, the spiral portion from the bar end A to the point F looks like a normal spiral same as any spiral arms in other regular spiral galaxies, so, it is highly suggested that the whole red line arm from the bar end A to the end of tail G was smoothly generated by one mechanism without interruption.

If the long straight tail was generated by the matter ejection due to galactic collision, then, the spiral arm section ABCDF and the long straight section FG would be generated by two completely different mechanisms, it is hard to believe that such two arm sections can be smoothly connected, although the possibility of such smooth connection cannot be completely excluded. The famous galaxy 4676 (also known as Mice galaxy) contains two colliding galaxies NGC 4676 A and NGC 4676B [8], one of the galaxies has a long straight tail as shown in Fig. 5. In this NGC 4676 galaxy, the long straight tail is caused by galactic matter ejection due to the galactic collision as described by Toomre, et al. [5], the straight tail seems to be directly ejected from the center of the galaxy and does not smoothly connect to any spiral structure of the galaxy.

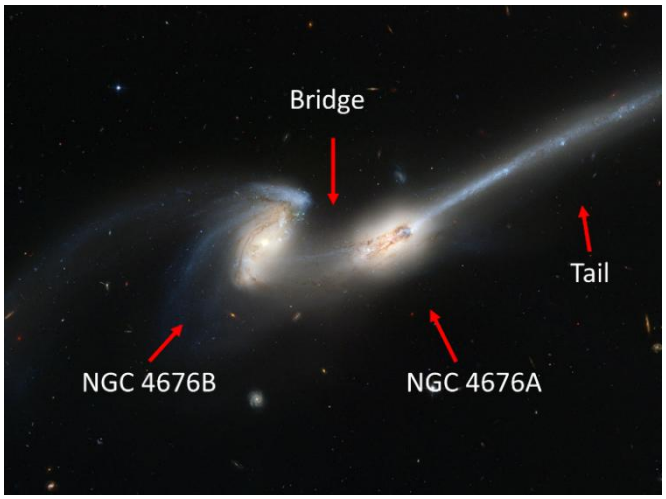

Fig. 5. The image of the NGC 4676 galaxy, known as Mice galaxy
Credit: NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M.Clampin (STScI), G. Hartig(STScI), the ACS Science Team, and ESA

Another characteristic of the red line arm is that the quality of the arm sequentially decreases along the arm line from A to G without any sign of destruction by the intruders, the arm section BCD has a well-defined profile with normal quality, the arm section DF is blocked by the central galactic disc, but the arm section FG gradually become looser and wider.

There is an apparent second spiral arm that starts at the bar end H, extends to I, to J, then to K as shown by the yellow line in Fig. 4, the quality of the arm from H to I is normal like other regular galaxies, but the quality of the arm is suddenly distorted at the point I and all arm section after the point I is seriously distorted and the arm material is scattered/dispersed as shown by the dash line area in the zoom-in image of the Tadpole head in Fig. 6, the arm section from J to K almost fades away and is barely seen. One may think that the two spots labeled as intruder 1 and intruder 2 may be a part of the spiral arm structure of the Tadpole galaxy; however, although such a possibility cannot be completely excluded, they are not fit into any of the smooth red and yellow spiral lines. A unique phenomenon in this galaxy is that the whole structure is not in the same plane, i.e., there is no common disc plane for both spiral arms and the central bars area, like a sandwich structure, in which, the short yellow arm is on top, the central bar disc is in the middle and the red arm is at the bottom. If the central bar area shown with orange color is the reference plane of the galaxy, then the red line arm clockwise spirals down (the galaxy rotates counterclockwise in this image) from A to F, therefore, the spiral is right-handed based on the definition of the handiness of the helix, same as the right-handed snail shell. However, the yellow line arm clockwise spirals up from the bar end H to IJK. This galaxy seems the only one with spiral chirality discovered at the moment.

Another important phenomenon shown in Fig. 6 is that Intruder 1 and Intruder 2 are very closely bound together, such a close bond can be seen clearly by the intergalactic bridge as labeled in the image. Therefore, the three galaxies are bundled together by their strong mutual gravitational interactions marked by the yellow arrows in Fig. 6, they are fast approaching each other and will merge in a very short time in the universe evolution time scale, however, such a “short time” is very long in our human’s time scale and may not be observable but is a blinking time in the universe evolution time scale.

The red line arm section BCD is well constructed without any distortion and any material dispersion. In contrast, the yellow line arm section IJ should have central symmetry relative to the red line arm section BCD and should have a similar quality, however, the yellow line section IJ is seriously distorted, and galactic material is dispersed/scattered, such serious distortion indicates that the bounded pair of the Intruder 1 and the Intruder 2 entered the Tadpole galaxy through the yellow line arm section IJ and distorted the section IJ by the gravitational force during the penetration. Therefore, the sudden destruction of the yellow line arm at the point I can be well justified.

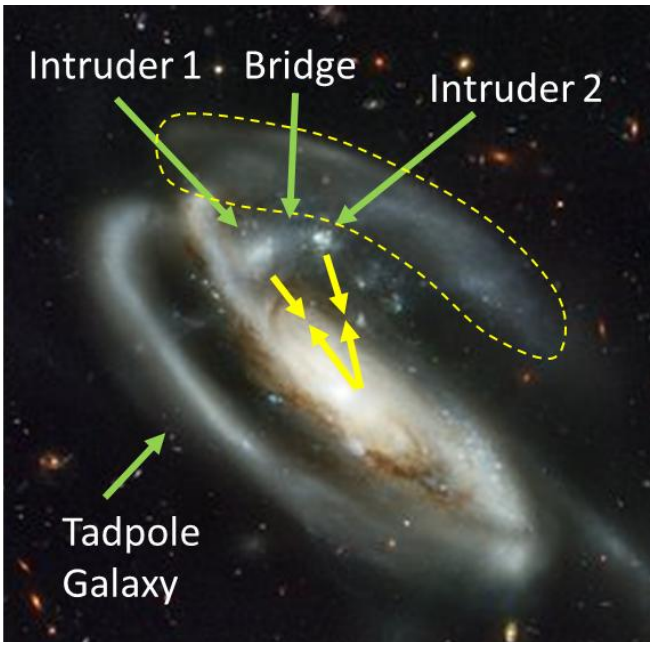

Fig. 6. Zoom-in image of Tadpole galaxy head

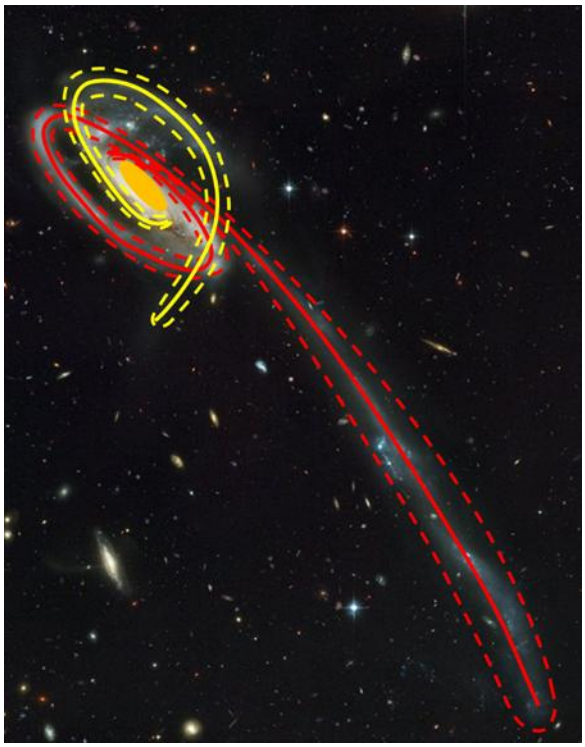

Fig. 7. Depicted spiral arm profile of the Tadpole galaxy

One of the fundamental problems in astronomy is how the spiral arms are created in the disc galaxies. The currently available theories for the formation of the spiral arms in the disc galaxies include Density Wave Theory and its variations [9-10], the swing amplification model [11], Manifold theory [12-16]. However, those models require disc galaxies with good disc planes and more or less evenly distributed galactic materials without gaps, so the density waves can propagate through the galactic materials to create spiral arms with the galactic materials

constantly moving in-and-out the spiral arms. However, in this Tadpole galaxy, the red line arm spirals downwardly and the yellow line arm spirals upwardly; in addition, there is a big gap without much galactic material between the red line arm section CD and the yellow arm section HI, the galactic material is well contained within small areas along the arm lines as shown by the dashed red and yellow lines in Fig. 7, the yellow line arm is much shorter than the red line arm. In such a scenario, it will be impossible for the density waves to propagate through the off-plane spiraling.

The ROTASE model may be able to explain the spiral formation in this galaxy. The ROTASE model was proposed by the author in 2019 [17-19], which is the short name of ROtating Two Arm Sprinkler Emission model, this model proposed that the central black hole of the galaxy emits antigravitational or non-gravitation matter through its two opposite directions, the emitted matter is named as X-matter because the property of the emitted matter is totally unknown, the “X” means unknown; The X-matter will move in a confined route for certain distance which is the half-length of the galactic bar, then, will be dragged by the rotating galactic disc matter after exiting the confined route, so the X-matter will move with the combination of its initial emission motion and the galactic disc flat rotation, the X-matter will be gradually converted to hydrogens and increase the local hydrogen density, such extra hydrogens from X-matter will promote new star formation and refuel the existing stars, as results, the local luminosity will be enhanced which is the observed spiral arms. The motion trajectory of X-matter motion can be calculated with a new set of galactic spiral equations developed from ROTASE model, regular spirals, rings, 8-shaped rings of spiral patterns can be precisely simulated by those spiral equations, various unusual spiral patterns can be explained. The X-matter emission at two opposites of the black hole can change with time in any format and can be unequal. The ROTASE model can explain the special pattern of the Tadpole galaxy also.

At long time (possible several hundreds of Myrs) ago, the UGC 10214, the Intruder 1 and the Intruder 2 formed a local cluster indicated by their mutual gravitational interaction by red arrows with substantial distances among them as illustrated in Fig. 8 left, the UGC 10214 was a regular galaxy like other spiral galaxies, did not have such long straight tail, the X-matter emission at two opposites of the central black hole were not equal, the rotation was slow. The three galaxies gradually moved to each other by their mutual gravitational forces, the motion velocity of UGC 10214 was quick compared to the galactic rotation velocity of UGC 10214, the motion trajectory of UGC 10214 can be illustrated in Fig. 8 right. At long time ago, the UGC 10214 was located at the location A, the Intruder 1 was at the location E and the Intruder 2 was located at the location F. The gravitational interactions among them were pulling them together and making them move to each other. The UGC 10214 moved along the red dashed line with a speed much faster compared to its rotation velocity, the central black hole emitted the X-matter at its two opposite directions unequally, one side emission was much weaker than the other side, so the stronger X-matter emission resulted in a strong arm, the other side X-matter emission was so weak that the arm was not visible. The strong arm looks straight, but it is highly suspected that it is still curved, due to the direction of the line of sight, it gives a fake impression of straight-line appearance, because the image looks closer to an edge-on image, the arm section FG could be curved if we look at the galaxy along the blue rotation axis in Fig. 4, which will give the face-on image.

When the UGC 10214 arrived at the location B, the gravitational interactions among the three galaxies became stronger and stronger, the Intruder 1 and the Intruder 2 were so close that they were bounded together and the pair acted like one object regarding to the interaction with the UGC 10214, the rotation of the galaxy UGC 10214 accelerated dramatically, the X-matter emission at the weak side also increased dramatically, the yellow line spiral arm shew up; in addition, the rotation axis of UGC 10214 changed due to the strong gravitational interaction between the pair of two small galaxies and the UGC 10214 galaxy, the rotation of the central part of the UGC 10214 acts like a spinning top, the strong gravitational tidal force pulls the central disc area of the UGC 10214 out of the BCDF plane, the rotation axis wobbling is responsible for the off disc plane spiral arm formation. The pair of the smaller galaxies entered the central area of the UGC 10214 through the yellow arm section IJ and seriously distorted the section. The current unique and beautiful Tadpole morphology of the galaxy UGC 10214 at location C is produced with the combination of all those effects, it is a magic artwork created by the nature. The morphology

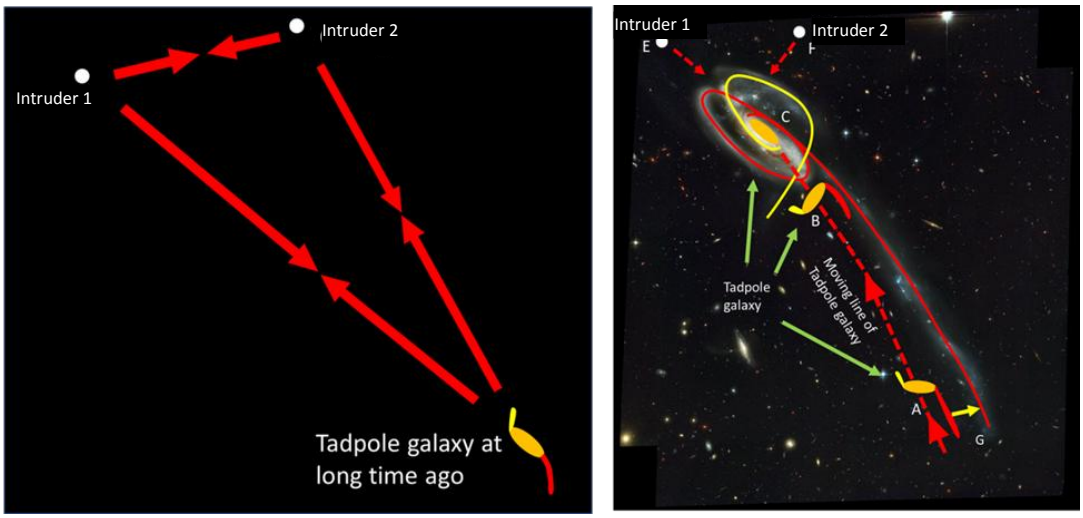

Fig. 8. Left is the illustration of the cluster of the Tadpole galaxy and two smaller galaxies at long time ago; right is the proposed moving lines of the three galaxies

of the local cluster of the three galaxies will change continuously in the future, the three galaxies will move closer and merge eventually in a fleeting moment of the universe time scale but too long in our human evolution time scale; the luminosity of the long tail will gradually decrease and become invisible after all hydrogens are consumed, but the tail still exists, could be deformed, more scattered, and detached from the Tadpole head.

3. ANOTHER KIND OF TADPOLE GALAXIES

There is another kind of Tadpole galaxies with morphologies like LEDA 36252 (also known as Kiso 5649), which has an elongated pattern with a bright clump at one end and a long tail shown in Fig. 9; some of those Tadpole galaxies have double bright clumps. Fig. 10 Shows a gallery of 36 Tadpole galaxies.

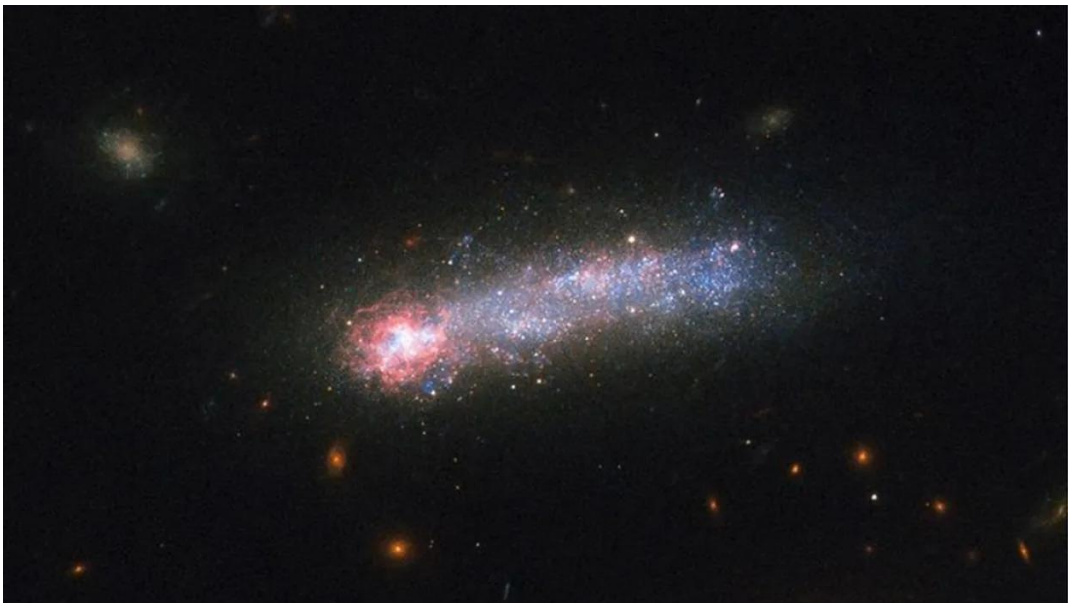

Fig. 9. the Tadpole galaxy LEDA 36252 or Kiso 5649

Credits: NASA, ESA, and D. Elmegreen (Vassar College), B. Elmegreen (IBM's Thomas J. Watson Research Center), J. Almeida, C. Munoz-Tunon, and M. Filho (Instituto de Astrofisica de Canarias), J. Mendez-Abreu (University of St. Andrews), J. Gallagher (University of Wisconsin-Madison), M. Rafelski (NASA Goddard Space Flight Center), and D. Ceverino (Center for Astronomy at Heidelberg University)

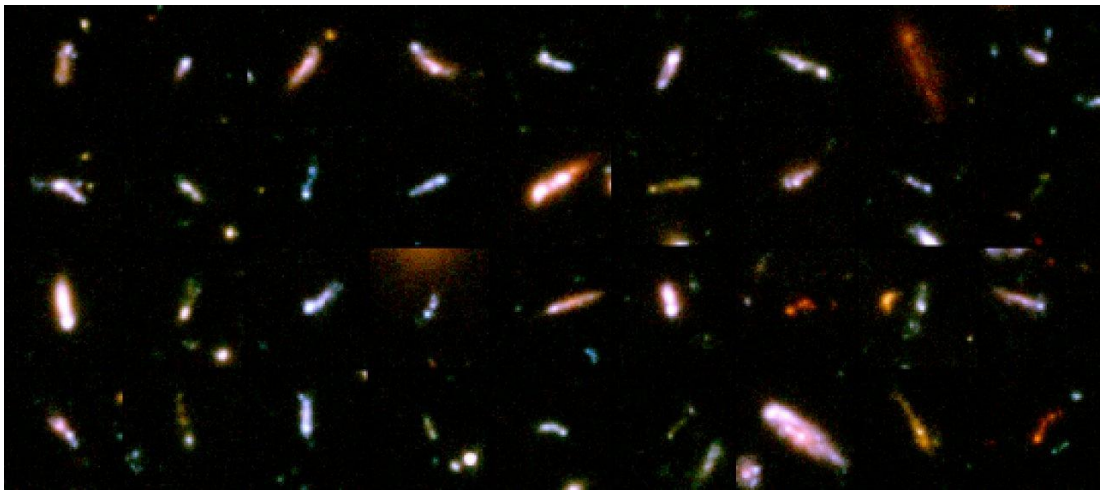

Fig. 10. A gallery of 36 Tadpole galaxies.
Credit: NASA, A. Straughn, S. Cohen, and R. Windhorst (Arizona State University), and the HUDF team (Space Telescope Science Institute)

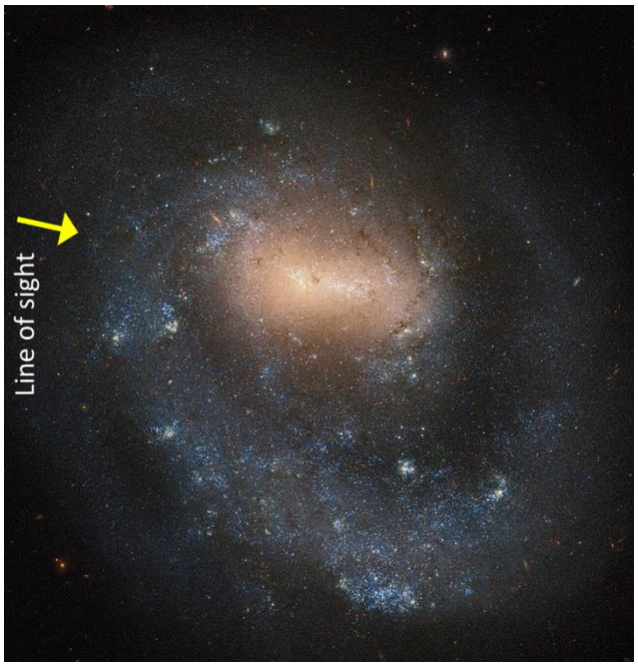

Fig. 11. Illustration of converting a one-arm galaxy to a Tadpole galaxy with edge-on and the line of sight parallel to the galactic bar. The one-arm galaxy NGC 4618 is viewed along the yellow line of sight parallel to the galactic bar, the image will be similar to LEDA 36252 shown in Fig. 9. Please note, the LEDA 36252 may not be the case

This type of Tadpole galaxies may have many origins. One of the origins is that if a galaxy with only one arm is viewed in edge-on with the line of sight parallel to the galactic bar, then, the image will be like the LEDA 36252 of Fig. 9. Such a view is illustrated in Fig. 11 with the famous one-arm galaxy NGC 4618.

If the line of sight in Fig. 11 gradually changes from parallel to the galactic bar to perpendicular to the galactic bar, the bright clump of the viewed edge-on image will gradually move to the center which will be a “normal” galaxy. The formation of the one-arm galaxy NGC 4618 is well explained by the ROTASE model [17].

If two galaxies are merging, it may result in a tadpole galaxy with double clumps as shown by the 5th galaxy of the second row in Fig. 10. It is very interesting that the Intruder 1 and the Intruder 2 in Fig. 6 formed a tadpole galaxy with double clumps, therefore, the Tadpole galaxy Arp 188 is actually a Tadpole galaxy residing inside of another Tadpole galaxy.

The tadpole galaxies may also be a result of a wind-swept mechanism similar to comets if they move through a dense intergalactic medium due to ram pressure [20].

Sanchez Almeida et al. [21] gave an extensive review of this kind of tadpole galaxies.

4. DISCUSSION

As demonstrated above, the formation of the special pattern of the Tadpole galaxy UGC 10214 can be nicely explained by the ROTASE model supported by the detailed information extracted from the image, the proposed mechanism for the formation of the special pattern is totally different from previous models. The UGC 1014 may not be a victim of a hit-and-run incident, instead, it is merging with two smaller galaxies. However, such illustration in this paper for the formation of the Tadpole galaxy is completely based on the interpretation of the available images. It is possible that other mechanisms could be proposed if the contents of the images can be interpreted in different ways or new findings in the future such as the spectroscopic data and other data. We have to rethink: are black holes at the centers of galaxies what we know them to be with our current knowledge?

5. CONCLUCION

Based on the information extracted from the image of Tadpole galaxy UGC 10214, the alternative mechanism for the formation of Tadpole galaxy is proposed:

The Tadpole galaxy and the other two smaller galaxies formed a well isolated local galactic cluster with mutual gravitational interactions. The three galaxies are approaching each other under gravitational forces. The Tadpole galaxy was initially a normal galaxy with unequal X-matter emission, one side of X-matter emission was strong, but other side X-matter emission was weak or no emission. The Tadpole galaxy initially had a fast motion to the pair of smaller galaxies with relatively slow rotation, the straight-like arm was generated in this period. When the three galaxies are close enough, the rotation of the Tadpole galaxy increased significantly, and the weak side X-matter emission increased significantly also, so, both arms are strong and clearly visible. Two smaller galaxies are close enough to form a pair with a galactic bridge, and the pair entered the Tadpole galaxy through its second (short) arm, seriously distorted the second arm. The strong mutual gravitational tidal forces among the three galaxies pulled the central disc area of the Tadpole galaxy out of its disc plane, changed the Tadpole rotation axis, this caused the morphology of the Tadpole galaxy like a sandwich structure, in which, one spiral arm is on top, the central bar disc is in the middle, and the other arm is at the bottom. The galaxy has a right-handed spiral chirality. The local cluster of the three galaxies will merge very soon in the time scale of the universe evolution, the morphology of the cluster will continue to change, the long straight tail will be invisible after all hydrogens are depleted. The two smaller galaxies formed a tadpole galaxy with double clumps; therefore, due to the huge size difference between the two different types of tadpole galaxies and the unique morphology, the current Arp 188 can be viewed as a hybrid of one type of tadpole galaxy parasitic inside of another type of tadpole galaxy, or humorously, a woman bearing a baby of another race through a transplant.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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