Colliding Galaxies

{Abstract *– In this segment of our "How far away is it" video book, we cover interacting or colliding galaxies.*

We describe what it means for galaxies to collide given the great distances between stars within each galaxy. We then take a look at some of the interacting galaxies photographed by the Hubble Telescope. These include: The Antennae Galaxies, The Mice, NGC 2207 with IC 2163; Apr 256; ESO 576-69; APR 142; NGC 6240; the Tadpole Galaxy; UCG 1810 with UCG 1813; The Mice; the spectacular APR 147; NGC 454; South America Galaxy; and ZW II 28.

We spend some time on peculiar galaxy NGC 7603 with its multiple red-shift objects that challenge well accepted theories on Dark Matter and Cosmology.

Next, we discuss how we go about seeing a process that takes a billion years by observing interactions at various stages along the process as understood by computer simulations. Here we show a few that illustrate the phases of an interaction: the initial approach with NGC 6786 and LEDA 62867; first contact with VV 304A and VV 304B; penetration with Mayall's Object; out the other side with ESO 77-14; wrap around with VV 705; and merge with The Owl.

We end with another simulation. This time it's the collision between Andromeda and the Milky Way.}

Introduction

> **[Music:** @00:00 *Vangelis – "Heaven and Hell" "3rd Movement" – Vangelis' "3rd Movement" on his 1975 album "Heaven and Hell" was chosen by Carl Sagan as the theme for his wonderful 'Cosmos' series.***]**

Welcome to our segment on interacting galaxies. Here's our old friend Andromeda. As we noted in earlier segments, Andromeda is heading towards the Milky Way. Andromeda will collide with the Milky Way, and start a one-billion-year long collision process.

If you recall, from our discussion about how far away stars are in the galaxy; for example, our nearest star, Proxima Centauri, is 4 light years away. Those large distances between stars mean that it's a million to one shot that any star will actually collide when the galaxies passed through each other. But the form and shape will change dramatically and change forever for the interacting galaxies themselves. The key factors are the shapes and relative masses of the colliding galaxies, the collision velocity, and the angle of collision – a glancing blow vs. a head on collision, they'll have different outcomes.

I'd like to show you a few of the over 100 interacting galaxies photographed by the Hubble Space telescope.

Interacting Galaxies NGC 4490 and NGC 4485 – 24 mly

Here we see NGC 4490 and NGC 4485. Together they form the system Arp 269. Over millions of years, their mutual gravitational attraction has dragged the two galaxies into each other. In this image, the two galaxies have moved through each other and are speeding apart again. [But the galaxies are likely to collide once more (within a few billion years).]

NGC 4490 was once a barred spiral galaxy, like the Milky Way. But now the outlying regions have been stretched out, resulting in its nickname - the Cocoon Galaxy.

Interacting Galaxies NGC 1510 and NGC 1512 – 38 mly

Here we're zooming into the tiny galaxy NGC 1510 and its colossal neighbor NGC 1512. The large galaxy to the left in this image, is classified as a barred spiral. The tiny NGC 1510 to the right, on the other hand, is a dwarf galaxy. Despite their very different sizes, each galaxy affects the other through gravity, causing slow changes in their appearances.

[The bar in NGC 1512 acts as a cosmic funnel, channeling the raw materials required for star formation from the outer ring into the heart of the galaxy. This pipeline of gas and dust in NGC 1512 fuels intense star birth in the bright, blue, shimmering inner disc known as a circumnuclear starburst ring, which spans 2400 light-years.]

Interacting Galaxies NGC 4298 and NGC 4302 – 55 mly

Here's an image of two galaxies: one is seen almost face-on and the other is seen edge-on. They were observed by Hubble in 2017 to celebrate its 27th year in orbit. In the face-on galaxy, we can see spiral arms and the blue patches of ongoing star formation and young stars. In the edge-on galaxy, we can see huge swathes of dust responsible for the mottled brown patterns. We also see a burst of blue to the left side of the galaxy indicating a region of extremely vigorous star formation. Their galaxy centers are 35,000 light years apart. At their closest points, the galaxies are separated from each other by only around 7,000 light-years. Given this very close arrangement, astronomers are intrigued by the galaxies' apparent lack of any significant gravitational interaction. [The only indication of an interaction is a faint bridge of neutral hydrogen gas -- not visible in this image – that appears to stretch between them.] The long tidal tails and deformations in their structure that are typical of galaxies lying so close to each other are missing completely.

Antennae Galaxies, NGC 4038 and 4039 – 62 mly

Named the Antennae Galaxies, these two spiral galaxies, drawn together by gravity, started to interact a few hundred million years ago. They are the nearest and youngest examples of a pair of colliding galaxies. This Hubble image has uncovered over 1,000 bright; young star clusters bursting to life in a brief, intense, brilliant "fireworks show". By the way, they are called the Antennae because the pair of long tails of luminous matter formed by the encounter resembles an insect's antennae.

[Music: @07:56 *Vangelis – "Conquest of Paradise" – Vangelis released this song in 1992. It was the theme for the movie "1492 Conquest of Paradise"***]**

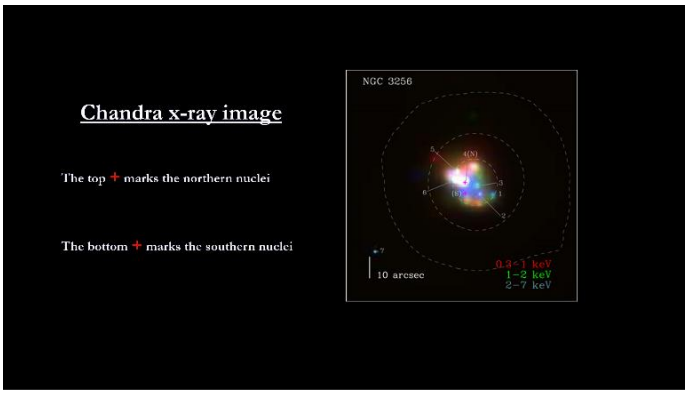
NGC 2207 and IC 2163 – 80 mly

Here's a spectacular sight. Strong tidal forces from the lager have distorted the shape of the smaller, flinging out stars and gas into long streamers stretching out a hundred thousand light-years toward the right-hand edge of the image.

NGC 3256 – 100 mly

Here we are zooming to NGC 3256. It is approximately the same size as our Milky Way and bears the marks of its past galactic collision in the extended luminous tails that sprawl out around the galaxy. These are thought to have formed around 500 million years ago during the initial encounter between the two galaxies, which today form just one. These tails are studded with young blue stars. It is believed that their birth was triggered by the collision. The brightness in the center of the galaxy makes it a starburst galaxy, host to vast amounts of infant stars born into groups and clusters.

As well as being lit up by over 1000 bright star clusters, the central region is home to crisscrossing threads of dark dust and a large disc of molecular gas spinning around two distinct nuclei — the relics of the two original galaxies. It takes an x-ray telescope to spot the second nuclei. In a few hundred million years, their nuclei will merge.



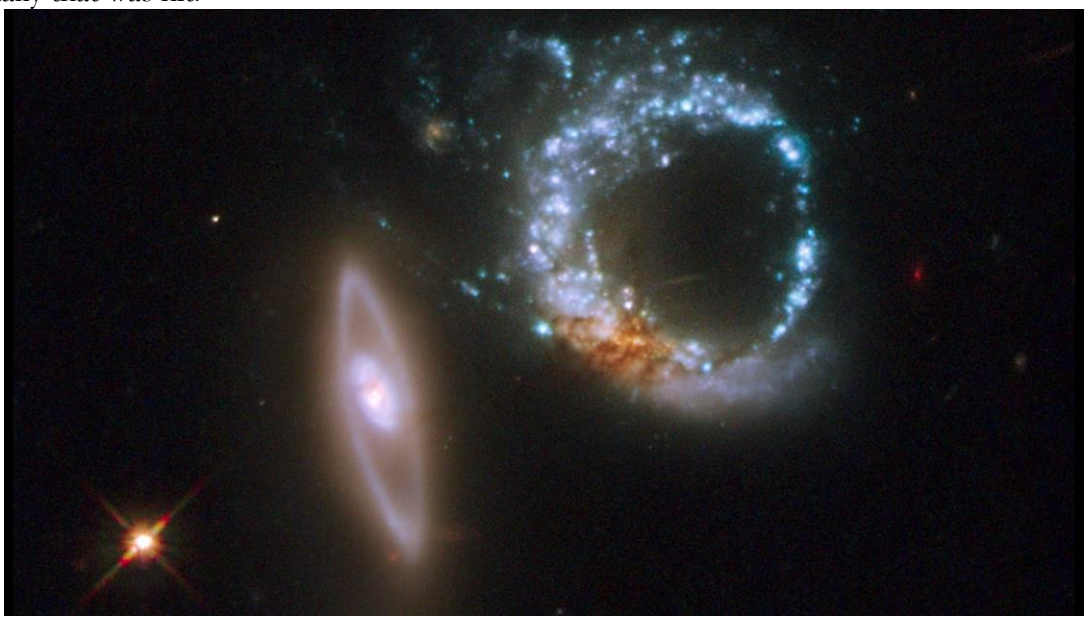
NGC 922 – 150 mly

Bright pink nebulae almost completely encircle this spiral galaxy. The ring structure and the galaxy's distorted spiral shape result from a smaller galaxy scoring a cosmic bull's-eye, hitting the center of NGC 922 some 330 million years ago. The small interloper can still be seen shooting away from the scene of the crash. As the small galaxy passed through the middle of NGC 922, it set up ripples that disrupted the clouds of gas, and triggered the formation of new stars whose radiation then lit up the remaining gas. The bright pink color of the resulting nebulae is a characteristic sign of this process.

In theory, if two galaxies are aligned just right, with the small one passing through the center of the larger one, the ring of nebulae should form a perfect circle, but more often the two galaxies are slightly off kilter, leading to a circle that, like this one, is noticeably brighter on one side than the other. The chances of seeing one of these galaxies nearby is therefore quite low. Despite the immense number of galaxies in the Universe, this is one of only a handful known in our cosmic neighborhood.

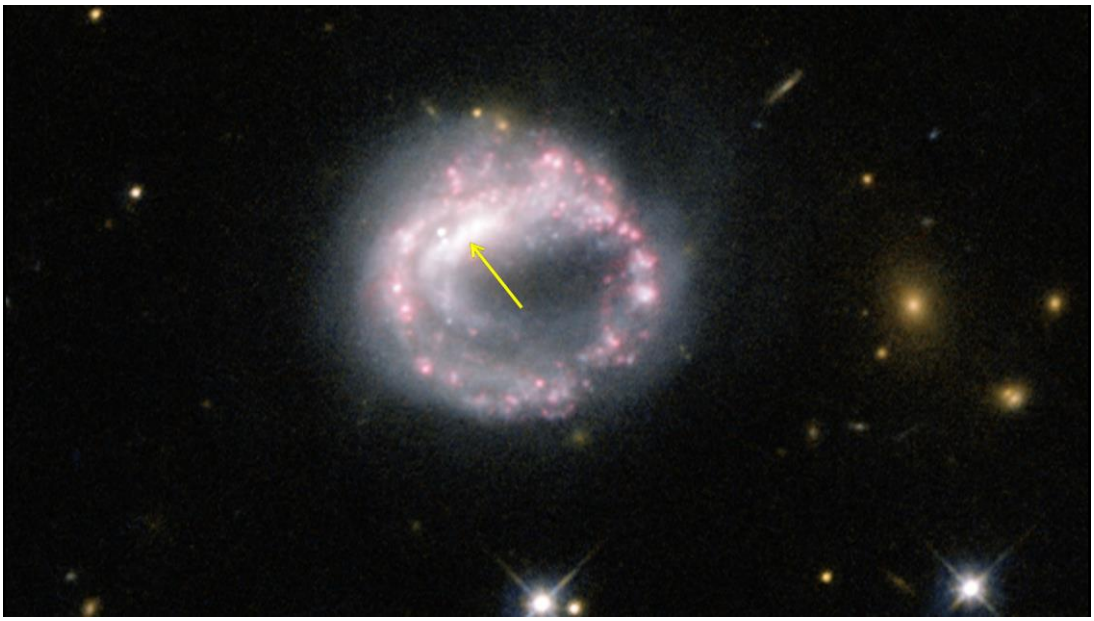
Arp 147 – 440 mly

Here we have another ring galaxy. This one more clearly demonstrates how the ring came from a direct collision. The relatively undisturbed one on the left most probably punched through the one on the right producing a burst of star formation appearing as the bright blue ring. Note the dusty reddish knot at the lower left of the blue ring probably marks the location of the original nucleus of the galaxy that was hit.



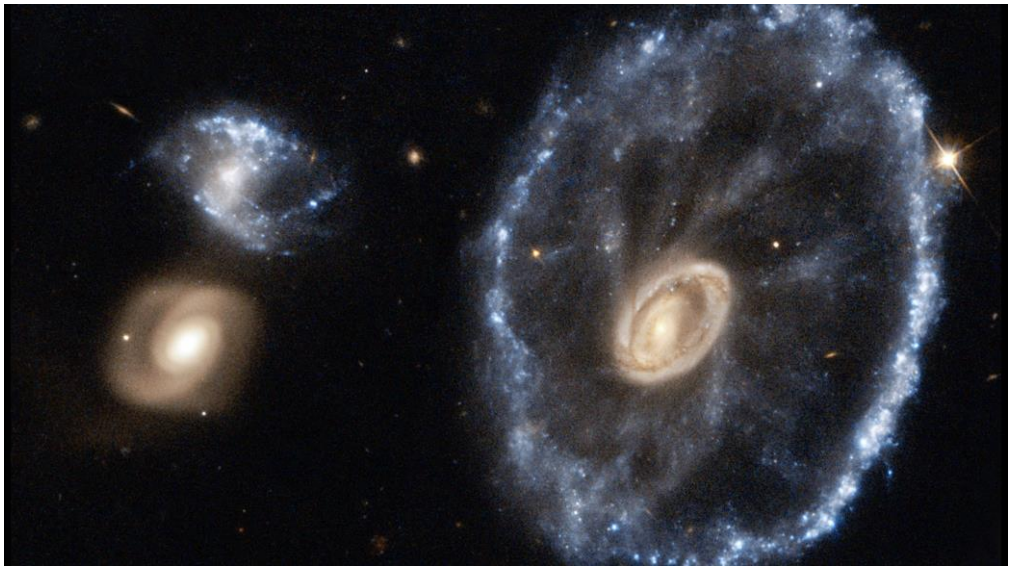
Zw II 28 – 319 mly

The sparkling pink and purple loop in Zw II 28 is not a typical ring galaxy due to the fact that it doesn't seem to have the usual visible central companion. For many years it was thought to be a lone circle on the sky, but observations using Hubble have shown that there may be a possible companion lurking just inside the ring, where the loop appears to double back on itself.



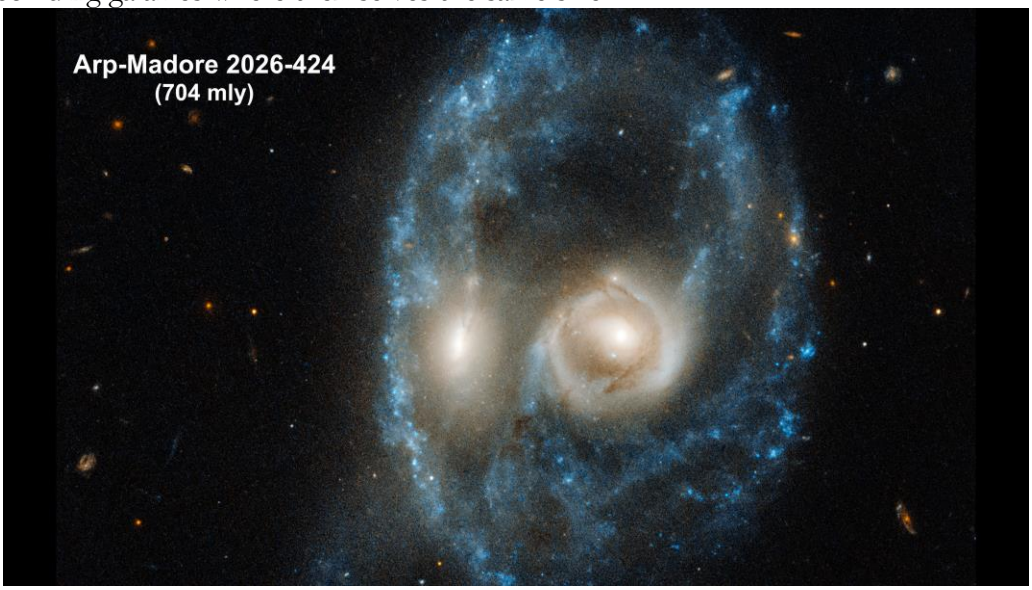
Cartwheel Galaxy – 500 mly

Lying about 500 million light-years away, the cartwheel shape of this galaxy is the result of a violent galactic collision. As with the other ring galaxies, the striking ring-like feature is a direct result of a smaller intruder galaxy — possibly one of two objects to the left of the ring — that careened through the core of the host galaxy. Presumably the Cartwheel Galaxy was a normal spiral galaxy like our Milky Way before the collision. This spiral structure is beginning to re-emerge, as seen in the faint arms or spokes between the outer ring and bulls-eye shaped nucleus. The ring contains at least several billion new stars that would not normally have been created in such a short time span and is so large (150,000 light-years across) that our entire Milky Way Galaxy would fit inside.



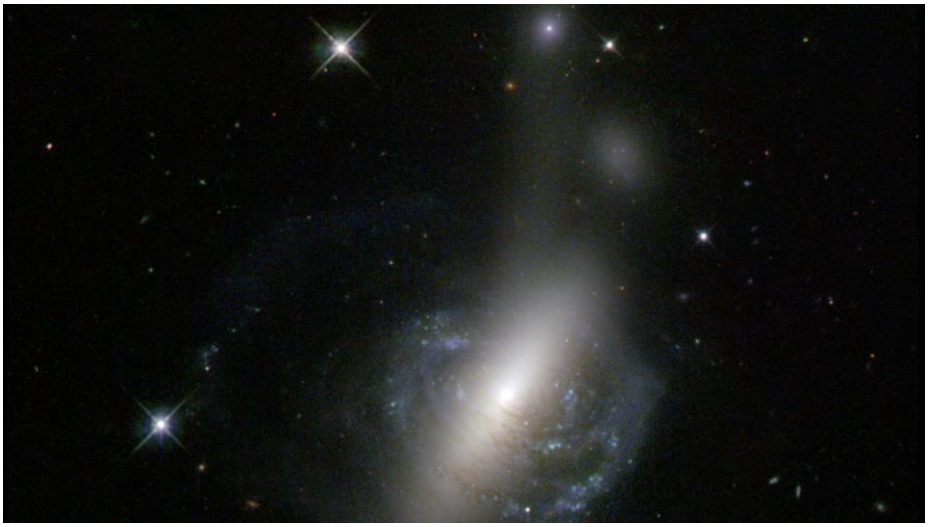
Arp-Madore 2026-426 – 704 mly

Here we are zooming into one more rare Ring galaxy 704 mly away. Only a few hundred Ring galaxies reside in our local supercluster. The fact that the two central bulges are the same size tells us that the colliding galaxies where themselves the same size.



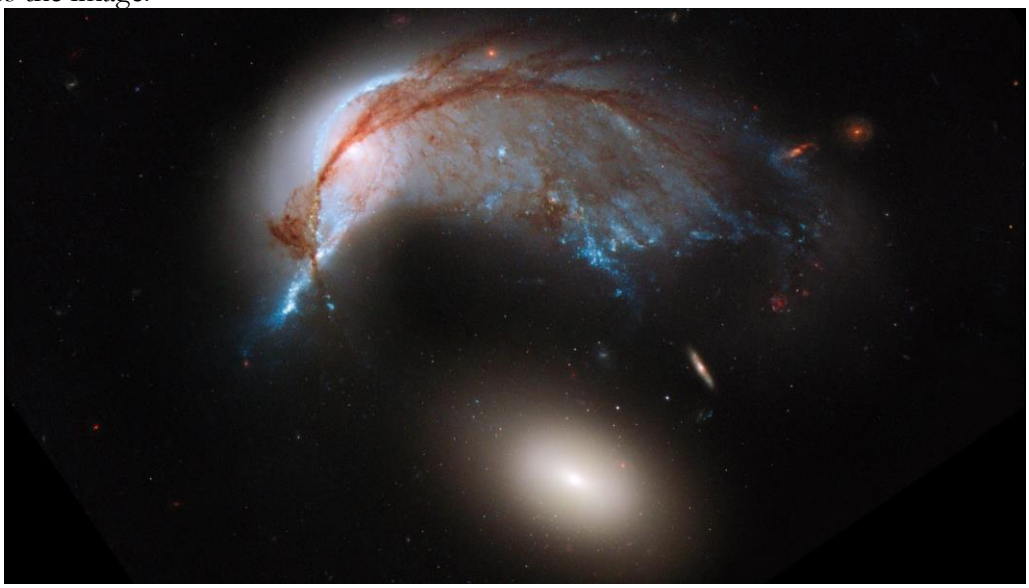
ESO 576-69 - 254 mly

This image from the NASA/ESA Hubble Space Telescope captures an ongoing cosmic collision between a spiral galaxy and a lenticular galaxy. The collision looks almost as if it is popping out of the screen in 3D, with parts of the spiral arms clearly embracing the lenticular galaxy's bulge. The bright spot in the middle of the plume above the galaxies is what makes this image unique. This spot is believed to be the nucleus of the former spiral galaxy, which was ejected from the system during the collision and is now being shredded by tidal forces to produce the visible stellar stream.



Arp 142 – 326 mly

These two galaxies resemble a penguin safeguarding its egg. This Hubble image of the interacting pair shows the blue, twisted form of galaxy NGC 2936 (the penguin), and its partner NGC 2937 (the egg). The remnants of 2936's spiral structure can still be seen. The former galactic bulge now forms the "eye" of the penguin, around which it is still possible to see where the galaxy's pinwheeling arms once were. These disrupted arms now shape the cosmic bird's "body" as bright streaks of blue and red across the image.



Arp 256 – 350 mly

Here we see a pair of barred spiral galaxies that have just begun a merger. Though their nuclei are still separated by a large distance, the shapes of the galaxies are significantly distorted. For example, the galaxy on the left contains very pronounced tidal tails — long, extended ribbons of gas, dust and stars. The bright blue areas are stellar nurseries. These vigorous bursts are triggered by the massive gravitational interactions, which stir up interstellar gas and dust out of which stars are created. The galaxies in this system will continue their merger for millions of years, before finally becoming a single galaxy.

Markarian 266 - 350 mly

Here we are zooming into Markarian 266 (aka NGC 5256). The odd structure of this galaxy is due to the fact that it is not one galaxy, but two — in the process of a galactic collision. It is composed of two disc galaxies whose nuclei are currently just 13,000 light-years apart. Their constituent gas, dust, and stars are swirling together igniting newborn stars in bright star formation regions across the galaxy. In addition, each merging galaxy contains an active galactic nucleus, where gas and other debris are fed into supermassive black holes.

NGC 6240, VV 617 – 400 mly

This is a peculiar, butterfly or lobster shaped galaxy consisting of smaller merging galaxies. With two giant black holes 3,000 light-years apart, which will drift toward one another and eventually merge together into a larger black hole. The merging process, which began about 30 million years ago, triggered dramatic star formation and sparked numerous supernova explosions. The merger will be complete in some tens to hundreds of millions of years.

Tadpole Galaxy, UGC 10214 – 420 mly

Here we have the "Tadpole" galaxy. Its distorted shape was caused by a small interloper, a very blue, compact galaxy visible in the upper left corner of the more massive Tadpole galaxy. Seen shining through the Tadpole's disk, the tiny intruder is likely a hit-and-run galaxy that is now leaving the scene of the accident. Strong gravitational forces from the interaction created the long tail of debris, consisting of stars and gas that stretch out more than 280,000 light-years. The other interesting thing here is that most of the stars in the background are all galaxies. There are 6,000 galaxies behind the Tadpole moving very deep into space.

[Additional info: Numerous young blue stars and star clusters, spawned by the galaxy collision, are seen in the spiral arms, as well as in the long "tidal" tail of stars. Each of these clusters represents the formation of up to about a million stars. Their color is blue because they contain very massive stars, which are 10 times hotter and 1 million times brighter than our Sun.

Two prominent clumps of young bright blue stars in the long tail are separated by a "gap" — a section that is fainter than the rest of the tail. These clumps of stars will likely become dwarf galaxies that orbit in the Tadpole's halo.**]**

Arp 273, UGC 1810 – 340 mly

Here is an especially photogenic group of interacting galaxies. The larger of the spiral galaxies has a dark disk that is tidally distorted into a rose-like shape by the gravitational tidal pull of the companion galaxy below it. A series of uncommon spiral patterns in the large galaxy is a tell-tale sign of interaction. The larger, outer arm appears partially as a ring, a feature seen when interacting galaxies actually pass through one another. This suggests that the smaller companion actually dived deep, but off-center, from the large galaxy.

[Additional info: The larger galaxy has a mass that is about five times that of the smaller galaxy. In unequal pairs such as this, the relatively rapid passage of a companion galaxy produces the lopsided or asymmetric structure in the main spiral. The image shows a tenuous tidal bridge of material between the two galaxies that are separated by tens of thousands of light-years from each other.**]**

The Mice, NGC 4676 – 300 mly

These colliding galaxies have been nicknamed "The Mice" because of the long tails of stars and gas emanating from each galaxy. The pair will eventually merge into a single giant galaxy. Computer simulations show that we are seeing two nearly identical spiral galaxies approximately 100 million years after their closest encounter. This is an example of what might happen to the Milky Way several billion years from now when it collides with Andromeda.

[Additional info: The long, straight arm is actually curved, but appears straight because we see it edge-on. The simulations also show that the pair will eventually merge, forming a large, nearly spherical galaxy (known as an elliptical galaxy). The stars, gas, and luminous clumps of stars in the tidal tails will either fall back into the merged galaxies or orbit in the halo of the newly formed elliptical galaxy.**]**

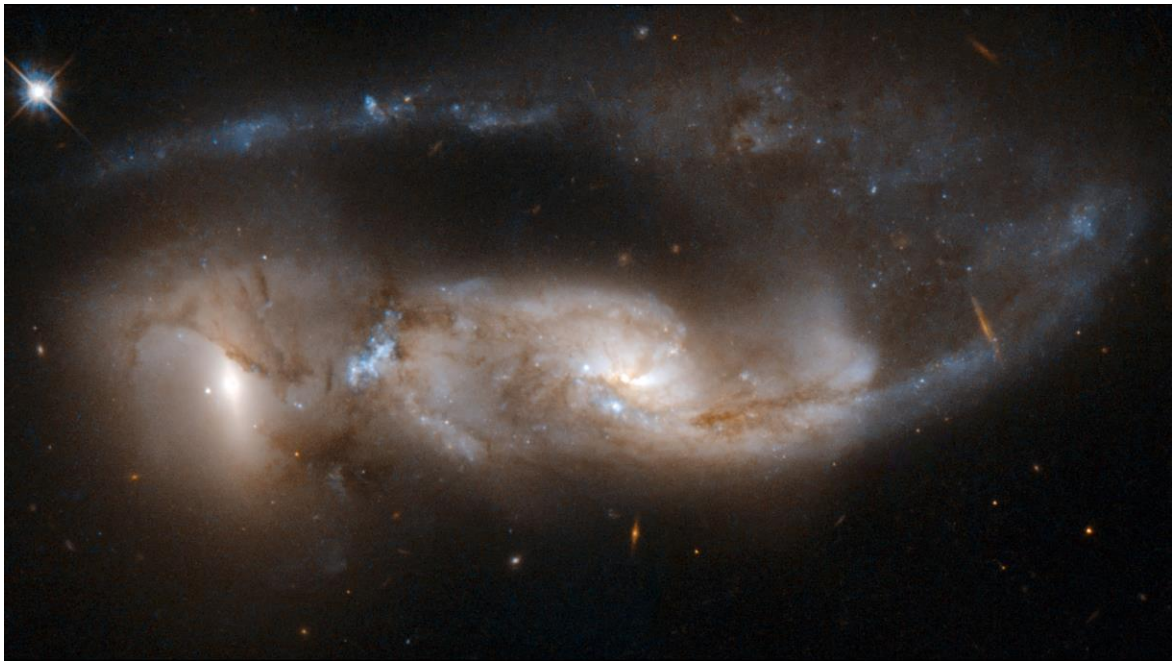
NGC 454 – 164 mly

NGC 454 is galaxy pair with a large red elliptical galaxy and an irregular gas-rich blue galaxy. The system is in the early stages of an interaction that has severely distorted both components. Although the dust lanes that stretch all the way to the center of the elliptical galaxy suggest that gas has penetrated that far, no signs of star formation are visible.

[The three bright blue knots of very young stars to the right of the two main components are probably part of the irregular blue galaxy.**]**

Arp 81 – 300 mly

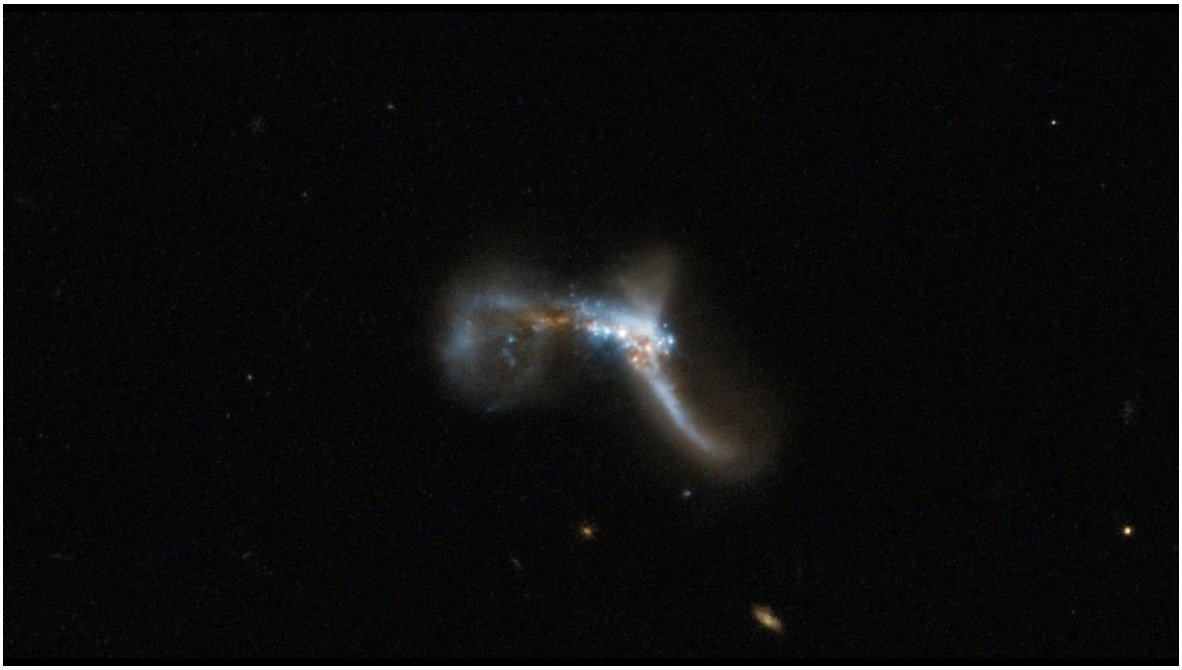
Arp 81 is a strongly interacting pair of galaxies, seen about 100 million years after their closest approach. It consists of NGC 6621 (to the right) and NGC 6622 (to the left). 6621 is a very disturbed spiral galaxy. The encounter has pulled a long tail out of it that has now wrapped behind its body. The collision has also triggered extensive star formation between the two galaxies. Scientists believe that Arp 81 has a richer collection of young massive star clusters than the notable Antennae galaxies we covered earlier.



[Music: @17:28 *Beethoven - Piano Concerto No. 3, Largo – Anton Dikov, from the album "Meditation: Classical relaxation" 2010***]**

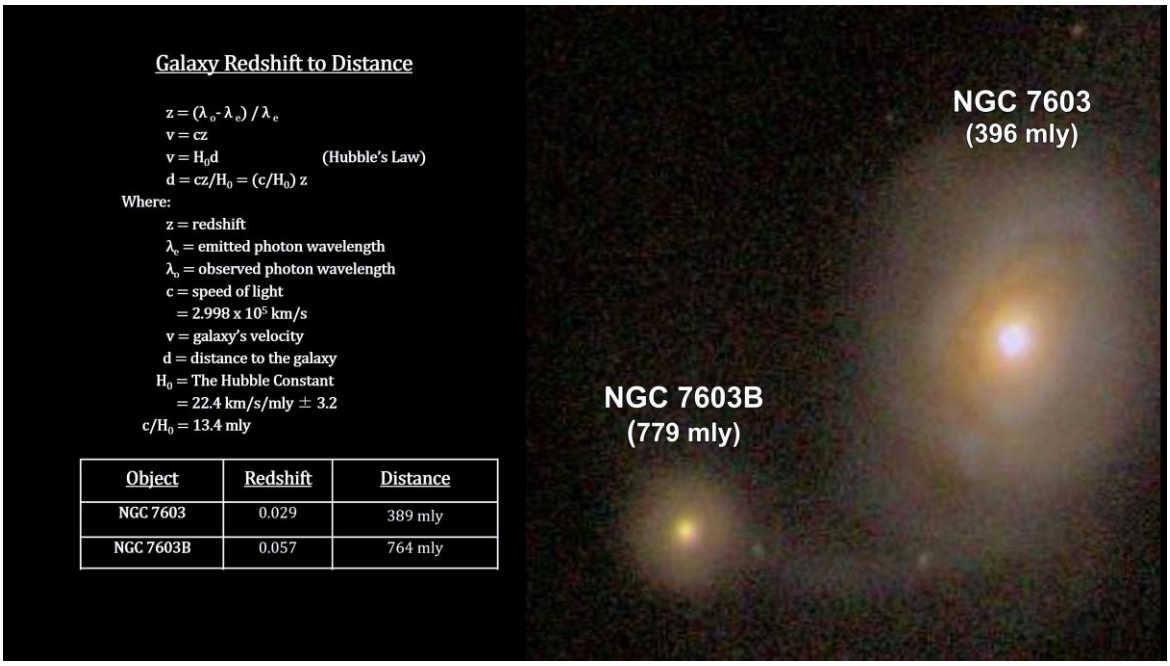
IRAS 22491-1808 - 1,079 mly

The contorted object captured by Hubble in this picture is known as the South America Galaxy. It is an ultraluminous infrared galaxy that emits a huge amount of light at infrared wavelengths. The reason for this intense infrared emission lies in an episode of strong star formation activity, which was set off by a collision between two galaxies. In the central region, which is very complex and disturbed, scientists have been able to distinguish two nuclei, remains of the two different galaxies that are currently colliding to form this new one. Other traces of the galactic collision are the three very noticeable tails in the image — two linear and one circular.



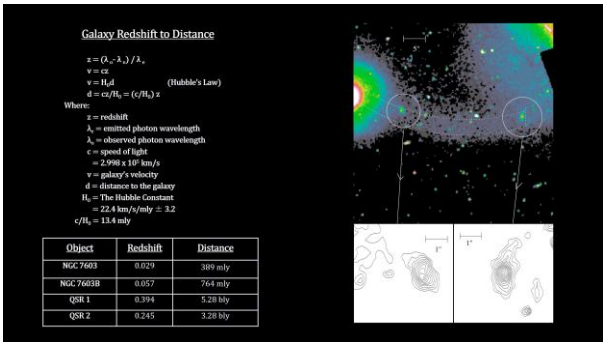
Peculiar galaxy NGC 7603

Here we have what astronomers call a peculiar galaxy. NGC 7603 and 7603B are identified as interacting according to the Sloan Digital Sky Survey. But they have a very interesting problem. As you recall from discussions on Hubble's law in our segment on the Virgo Supercluster, an object's redshift gives us its distance. But in this case, the redshift for 7603 is a good deal smaller than the redshift for 7603B. If redshift is only cased by the expansion of the universe, these two galaxies are to far apart to be interacting as they appear to be. Looking at it the other way around, if they are actually interacting, then there must be more than one explanation for redshift.



On top of that, two quasi-stellar objects (aka Quasars) have been found in the filament connecting the two main galaxies. [They are officially categorized as HII galaxies with very vigorous star formation. The rest of the filament and 7603B lack star formation. HII Galaxies are compact dwarf galaxies with the same optical spectra of Giant HII regions like the ones we covered in our chapter on the Milky Way. The thing is that the QSRs' redshifts are dramatically larger than either large galaxy.] That puts them billions of light years further away than the galaxy system they appear to be a part of. These numbers have held up under significant spectroscopic analysis. The standard explanation is that they are actually not a part of the NGC 7603 system and their apparent position is a coincidence. But the odds that this is true are extremely small. Plus, there are other interacting galaxy observations with similar redshift problems. Some astronomers are calling for a new physics to explain the situation. This would put the expansion of the Universe and the corresponding Big Bang theory in jeopardy. Time will tell.

[Some astronomers suggest that electrons and other atomic constituents can be created with initially smaller mass. Then smaller atomic transition emissions and absorptions would result in new galaxy light shifted to the red. As the galaxy ages, its atomic parameters asymptotically approach that of older matter. Such a theory would upend all of modern cosmology and particle physics.]



The Collision Process

Of course, we cannot watch a collision of galaxies unfold. It takes billions of years. But we do see colliding galaxies in various stages of a collision process across the cosmos. The ones we saw are only a few of the hundreds photographed by the Hubble telescope. Computer models show how galaxies of similar sizes might be transformed during a collision. The next six interacting galaxies represent various phases in the billion-year collision process.

NGC 6786, LEDA 62867

This Hubble image displays a beautiful pair of interacting spiral galaxies with swirling arms. The smaller of the two seems to be safe for now, but will probably be swallowed by the larger spiral galaxy eventually. **[**There is already some disturbance visible in both components.**]**

VV 340

Here is a pair of very gas-rich spiral galaxies in their early stages of interaction.

Arp 148 Mayall's object

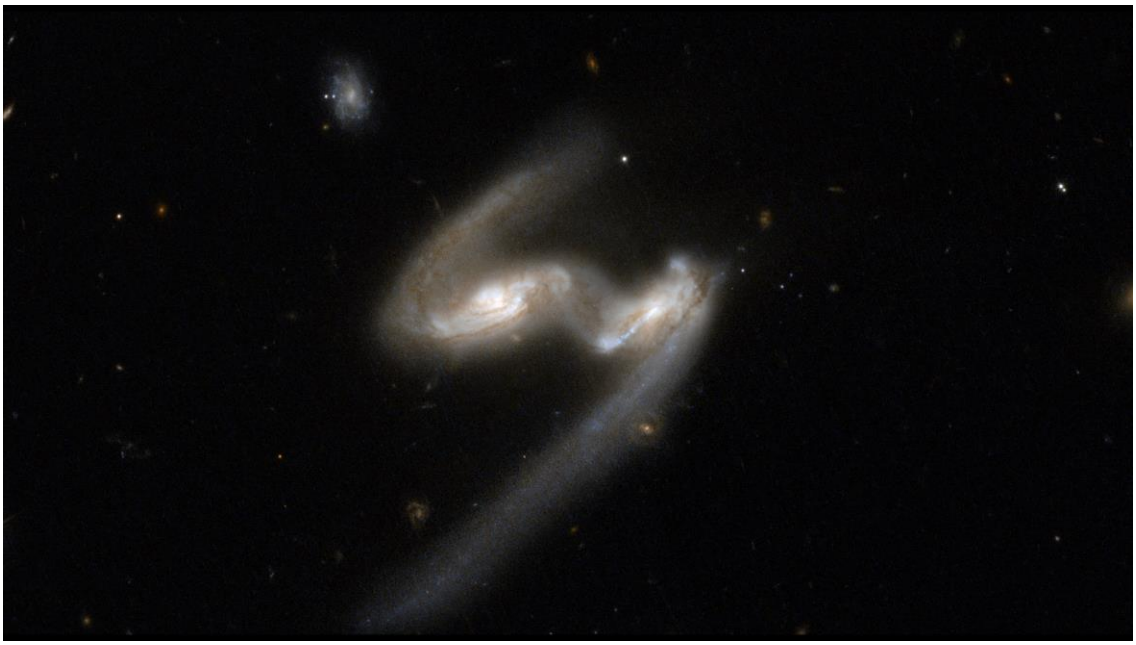
Here we see the staggering aftermath of an encounter between two galaxies, resulting in a ring-shaped galaxy and a long-tailed companion. The collision between the two parent galaxies produced a shockwave effect that first drew the matter into the center and then caused it to propagate back outwards in a ring. The elongated companion perpendicular to the ring suggests that Arp 148 is a unique snapshot of an ongoing collision.

ESO 77-14

This Hubble image is a stunning snapshot of a celestial dance performed by a pair of similar sized galaxies. Two clear signatures of the gravitational tug of war between the galaxies are:

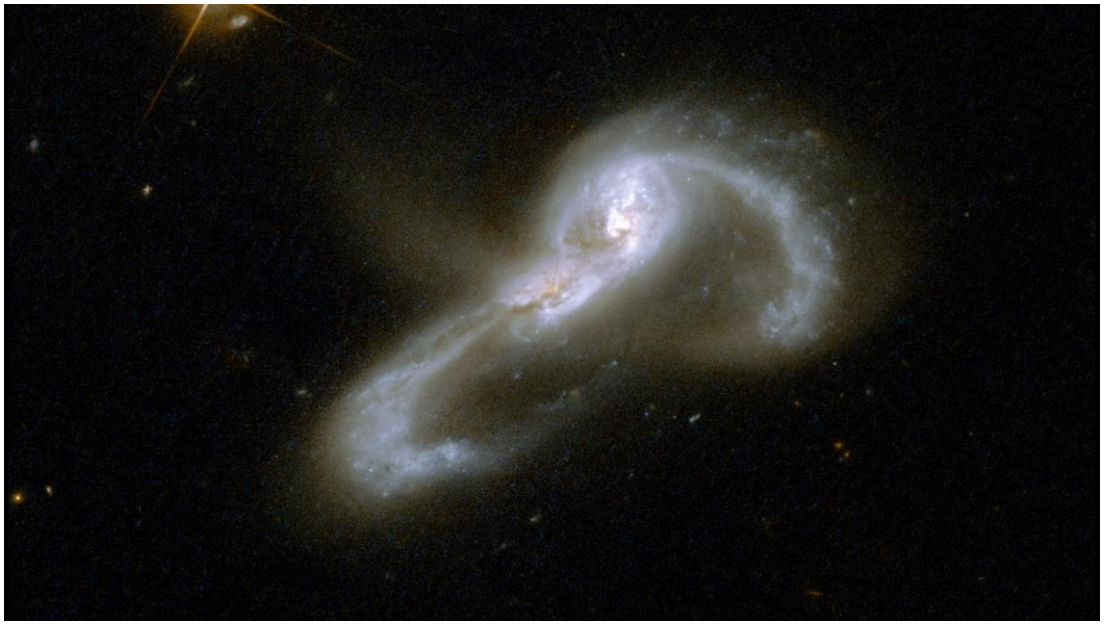
1. The bridge of material that connects them
2. And the disruption of their main bodies.

The dust lanes between the two galaxy centers show the extent of the distortion to the originally flat disks that have been pulled into three-dimensional shapes.



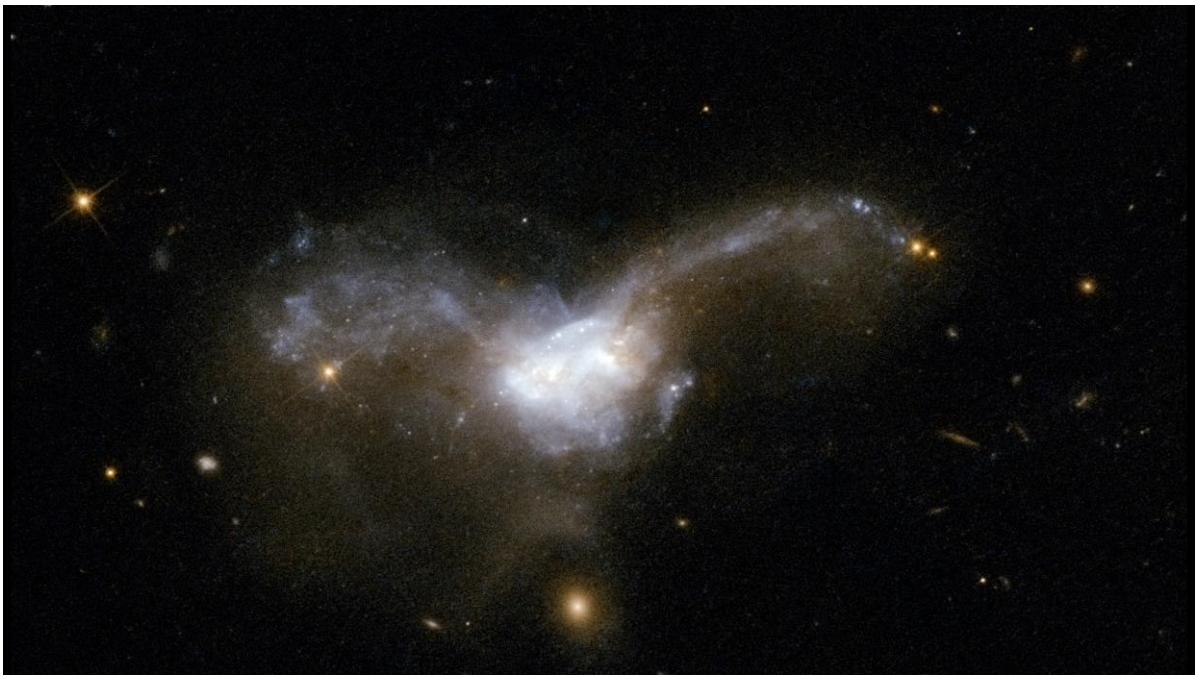
VV 705

Here we have two galaxies that seem to be embracing each other. Two long, highly curved arms of gas and stars emerge from a central region that has two cores. The two cores are 16,000 light-years apart. The pair is thought to be midway through a merger.

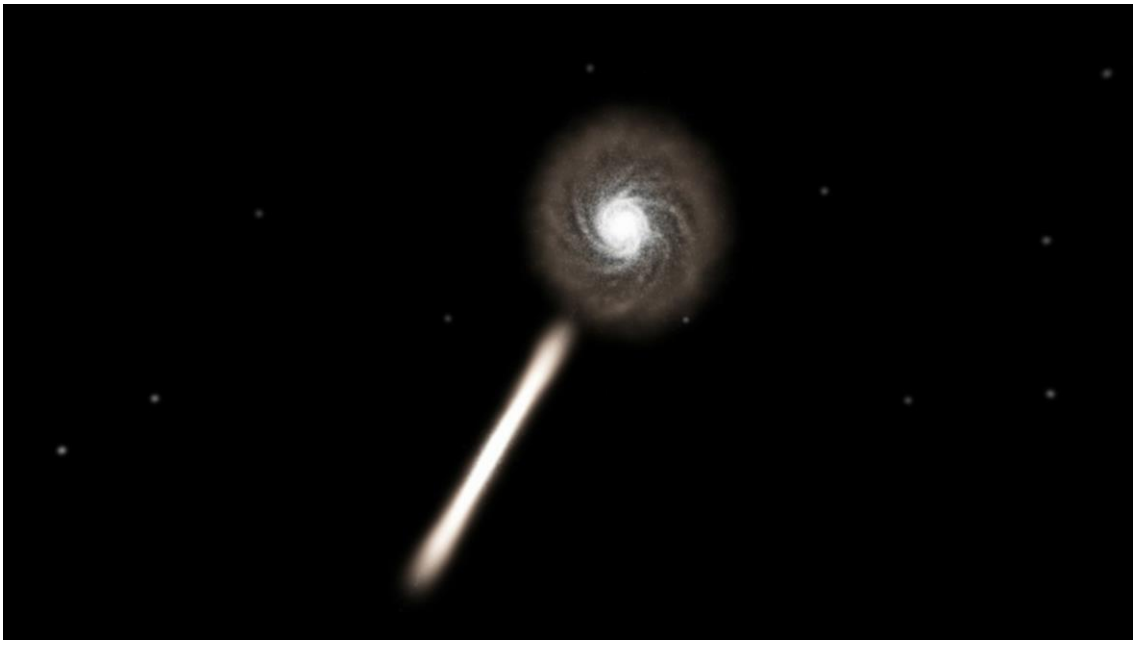


ESO 148-2 the Owl

This is a beautiful object that resembles an owl in flight. It consists of a pair of former disk galaxies undergoing a collision. The cores of the two individual galaxies - seen at the center of the image - are embedded in hot dust and contain a large number of stars. Two huge wings sweep out from the center and curve in opposite directions. These are tidal tails of stars and gas that have been pulled from the easily distorted disks of the original galaxies.

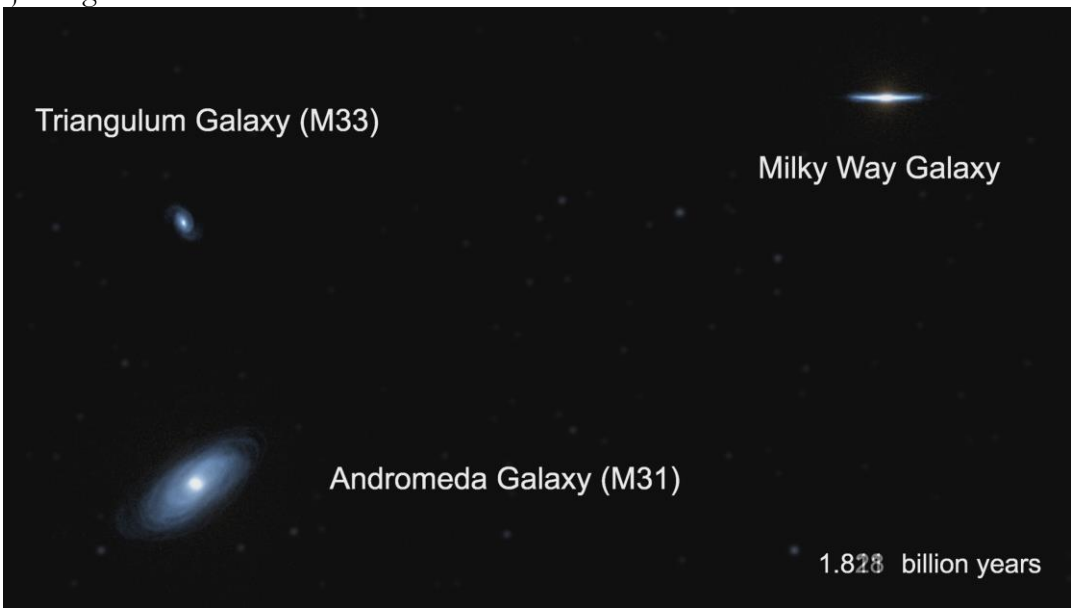


Here's a computer simulation. You'll recognize the last six objects we discussed at key points along the way.



Milky Way - Andromeda Collision

The three largest galaxies in our Local Group are our Milky Way, Andromeda and Triangulum. This Hubble Space Telescope visualization of a computer simulation depicts their joint evolution over the next several billion years and ends with the massive collision between the Milky Way and Andromeda. Hubble observations indicate that the two galaxies, orbiting the Local group's center of gravity, will impact each other in a head-on collision around 4 to 4.5 billion years from now. On the first pass, the thin disk shapes of these spiral galaxies will be strongly distorted by the encounter. Subsequent passes will turn the two spiral galaxies into one giant elliptical galaxy. Their cores will merge along with their central supermassive black holes. The Triangulum galaxy will continue to orbit the merged pair through the end of this computer simulation, although other computer models show it joining the collision.



Colliding Galaxies Conclusion

In the How Far Away Is It video book, we have covered distances for the Earth, our solar system, the Milky Way, and galaxies from our Local Group, out to our Local Superclusters. In our final segment, we'll put it all together as we consider the Cosmos as a whole and look forward to the launch of the James Web Space Telescope.