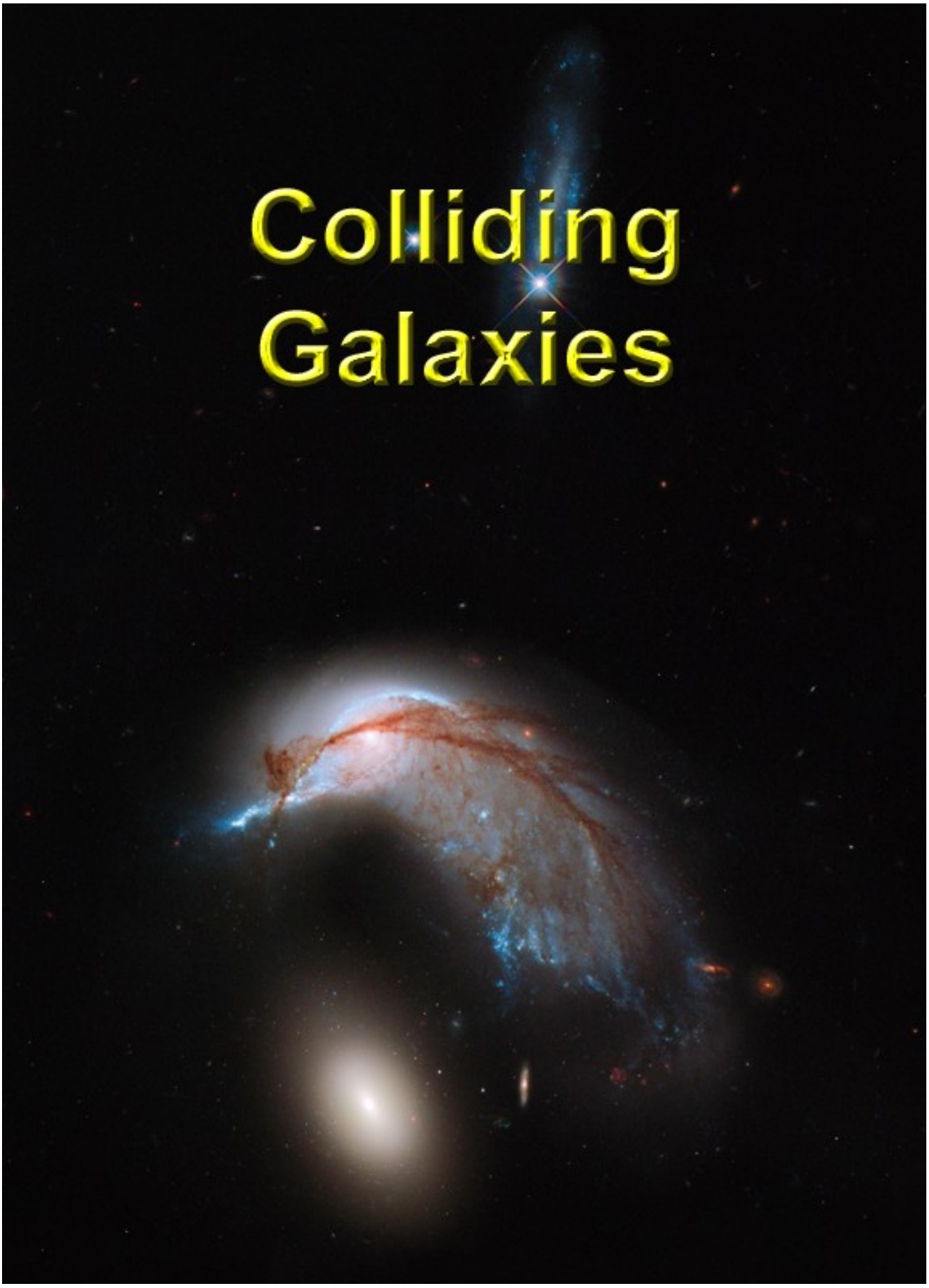

Colliding
Galaxies

Colliding Galaxies

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

We begin with the trajectory of Andromeda with respect to our Milky Way. They are on a collision course. 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, 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; IRAS 22491-1808; peculiar galaxy NGC 7603 with its multiple red-shift objects; and ZW II 28 where we calculate its distance from its redshift.

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 are a few that illustrate the phases of an interaction: the initial approach – NGC 6786 with LEDA 62867; first contact – VV 304A with VV 304B; penetration – Mayall's Object; out the other side – ESO 77-14; wrap around – VV 705; merge – The Owl. We then show the computer simulation of a collision and highlight the above galaxies along the way.

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

Introduction

> **[Music:** *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. It has the right sound for beginning our segment on colliding galaxies.***]**

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. If the transverse side to side velocity is as we currently think it is, then Andromeda will collide with the Milky Way in 5 to 10 billion years from now, and start a one billion year long collision process.

But 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.

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.

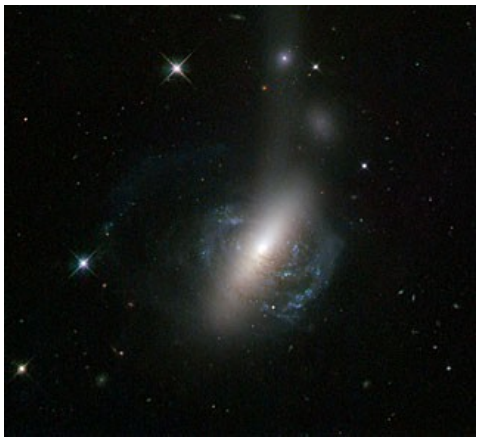
NGC 2207 and IC 2163 – 80 mly

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. **[**This head-on collision my well result in the collision of the central massive black holes.**]**

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.

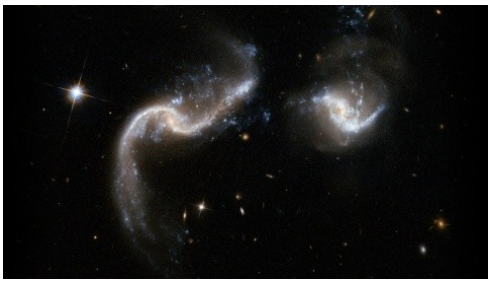


Arp 142 – 326 mly

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.

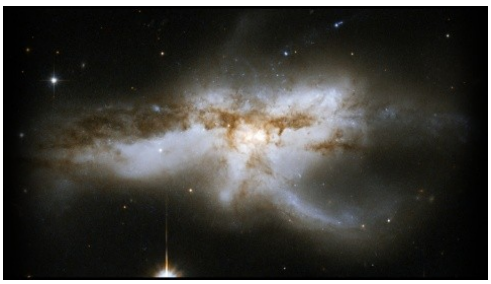
Arp 256 - 350 mly

This is a stunning system of two spiral galaxies in an early stage of merging. The Hubble image displays the two galaxies with strongly disrupted shapes and an astonishing number of blue knots of star formation that look like exploding fireworks. **[**The galaxy to the left has two extended ribbon-like tails of gas, dust and stars.**]**



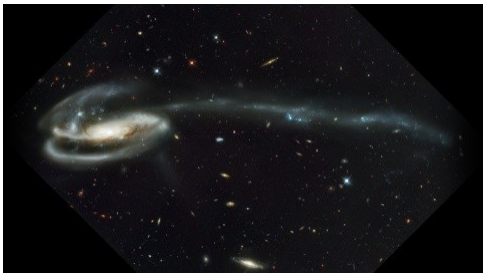
NGC 6240, VV 617 – 400 mly

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.



UGC 10214, Tadpole Galaxy – 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.**]**

> **[Music:** *Simon Wilkinson – "Exodus" – Simon Wilkinson's "Exodus" with its slow and pensive orchestral strings slowly building in intensity and atmosphere to introduce muted and mournful French horns. This creates a great sound for interacting galaxy gazing.***]**

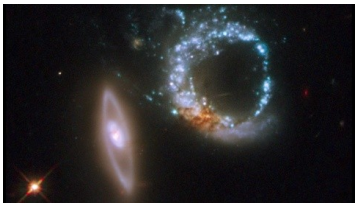
NGC 4676, the Mice – 300 mly

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.**]**

Arp 147 – 440 mly

Here we have a spectacular pair of galaxies. 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.



[Additional info: The third bright object on the left is a relatively nearby star. The blue ring was most probably formed after the galaxy on the left passed through the galaxy on the right. Just as a pebble thrown into a pond creates an outwardly moving circular wave, a propagating density wave was generated at the point of impact and spread outward. As this density wave collided with material in the target galaxy that was moving inward due to the gravitational pull of the two galaxies, shocks and dense gas were produced, stimulating star formation.**]**

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.**]**

2MASX J00482185-2507365 – 780 mly

Here's a rare alignment between two spiral galaxies. The outer rim of a small, foreground galaxy is silhouetted in front of a larger background galaxy. Skeletal tentacles of dust can be seen extending beyond the small galaxy's disk of starlight. Such outer dark dusty structures, which appear to be devoid of stars, like barren branches, are rarely so visible in a galaxy because there is usually nothing behind them to illuminate them.

Astronomers have never seen dust this far beyond the visible edge of a galaxy. They do not know if these dusty structures are common galaxy features.

Astronomers calculated that the background galaxy is 780 million light-years away. They have not yet calculated the distance between the two galaxies, although they think the two are relatively close, but not close enough to interact just yet.

[Additional info: Understanding a galaxy's color and how dust affects and dims that color are crucial to measuring a galaxy's true brightness. By knowing the true brightness, we can calculate the galaxy's distance.**]**

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.

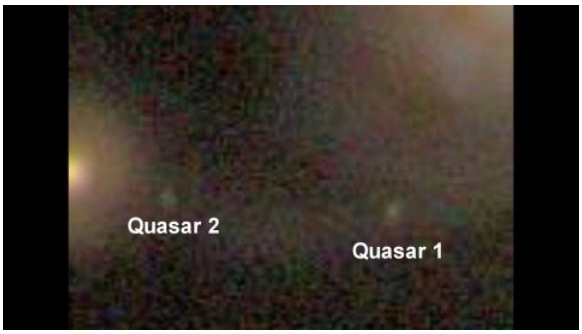
Peculiar galaxy NGC 7603

[Music: *Vangelis – "Conquest of Paradise" – Vangelis released this song in 1992. It was the theme for the movie "1492 Conquest of Paradise" - fitting for the conquest of one galaxy over another as they collide.***]**

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 galaxy superclusters, 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 NGC 7603B.

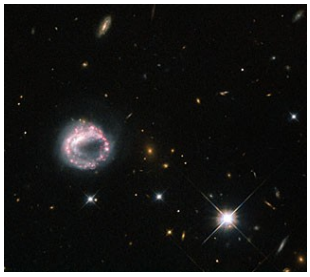
If redshift is only caused by the expansion of the universe, these two galaxies are too far apart to be interacting as they appear to be. Looking at it the other way around, if they are actually interacting, than there must be more than one explanation for redshift. This would put the expansion of the Universe and the corresponding Big Bang theory in jeopardy.

A deep study of this pair of galaxies was conducted to see if we could find an explanation. What the study found was two Quasars inside the filament connecting the two galaxies. And these quasars have even greater, in fact much greater redshifts. So this remains a mystery with potentially significant consequences.



Zw II 28 – 319 mly

Galaxies can take many forms — elliptical blobs, swirling spiral arms, bulges, and discs are all known components of the wide range of galaxies we have observed in are nearby superclusters. However, some of the more intriguing objects in the sky around us include ring galaxies like the one pictured here.



Ring galaxies are mysterious objects. They are thought to form when one galaxy slices through the disc of another, larger, one. The disruption upsets the material in both galaxies, causing it to redistribute to form a dense central core, encircled by bright stars.

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.

In my research, I was not able to find the distance to Zw II 28. So let's take this opportunity to calculate the distance from the redshift.

We know from our discussion of the Doppler Effect in our Planetary Nebula segment that the velocity v of the galaxy is equal to the speed of light c times the ratio of the change in the spectral line length divided by the spectral line length at rest. This can be written as:

$$v = c(\Delta\lambda/\lambda)$$

$$v = c((\lambda_{observed} - \lambda_{atrest})/\lambda_{atrest})$$

$$v = c(\lambda_{observed}/\lambda_{atrest} - 1)$$

$(\lambda_{observed}/\lambda_{atrest} - 1)$ is the definition of redshift z. So we have

$$v = cz.$$

From our discussion on Hubble's Law in the Virgo Supercluster segment, we have the distance d is equal to the velocity v divided by the Hubble constant. Substituting cz for v, we get:

$$d = cz/H_0.$$

For Zw II 28, the redshift is measured to be 0.02863. Plugging this, the speed of light and Hubble's constant into the equation we have the distance to Zw II 28 as:

$$d = (186000 \text{ mi/s} \times 0.02863) / (13.6 \text{ mi/s / mly})$$

$$= 319 \text{ mly}$$ to Zw II 28.

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.

[Music: *We return to Simon Wilkinson's "Exodus.*]

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. **[**One arm, curving clockwise, stretches to the top of the image where it makes a U-turn and interlocks with the other arm that curves up counter-clockwise from below.**]** 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.

[Music: *Ramin Djawadi – "Game of Thrones Main Title" – In the game of thrones, your either win or you die. So it goes with galaxies.***]**

Next I'm going to show you a very interesting computer simulation. You'll recognize the last six objects we discussed at key points along the way. We'll finish this segment with a second simulation – the collision between Andromeda and the Milky Way!