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The Milky Way's Collision with the Andromeda Galaxy

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The Milky Way's Collision with the Andromeda Galaxy

On a dark autumn night, a faint oblong object several times the width of the full Moon can be seen to the northeast of the Great Square of Pegasus, in the neighboring constellation of Andromeda, the Princess. The object has piqued the interest of astronomers for centuries. In approximately 964 AD, the Persian astronomer Abd al-Rahman al-Sufi first cataloged it in his *Book of Fixed Stars* as a "small cloud." In 1764, Charles Messier designated the object M31 in his catalog of nebulas. Over time it became known as the "Great Nebula in Andromeda." Astronomer Isaac Roberts, who lived in Sussex, England, was the first to photograph the object, revealing its spiral structure in 1887. Most astronomers at the time assumed it was a nearby whirlpool of dust and gas around a newborn star, but its distance and relative motion to the Sun were unknown.

A quarter of a century later, American astronomer Vesto Slipher determined the object's velocity with respect to our solar system. He did this by measuring its Doppler shift, the displacement of an object's spectrum from that of a stationary source. Wavelengths of light emitted by a source moving away from an observer are seen to shift toward the red end of the spectrum; those from an approaching source shift to the blue. He concluded that the object—whatever it was—was moving toward the Sun at about 250,000 miles (402,336 kilometers) per hour—fast enough to travel from the Moon to Earth in about 60 minutes.

Thirteen years later, in 1925, Edwin Hubble used the largest telescope of his day to identify individual stars within M31 and calculate their distances. Hubble found that the stars in M31 were more than 25 times farther away than the most distant stars known. This conclusively demonstrated that M31, the Great Nebula in Andromeda, was not a nebula within the Milky Way at all, but a separate celestial system containing billions of its own stars. Such systems, of course, are now called *galaxies* and most of them are immensely remote. Current measurements of M31 place it at a distance of 2.5 million light-years from our own galaxy, the Milky Way. But M31 is "local" when compared with other galaxies found at distances reaching as far as 10 billion light-years away. The Andromeda and Milky Way galaxies are, in fact, the two most massive galaxies in the *Local Group* of about 30 to 50 galaxies travelling through space as a collection that is approximately 10 million light-years across.

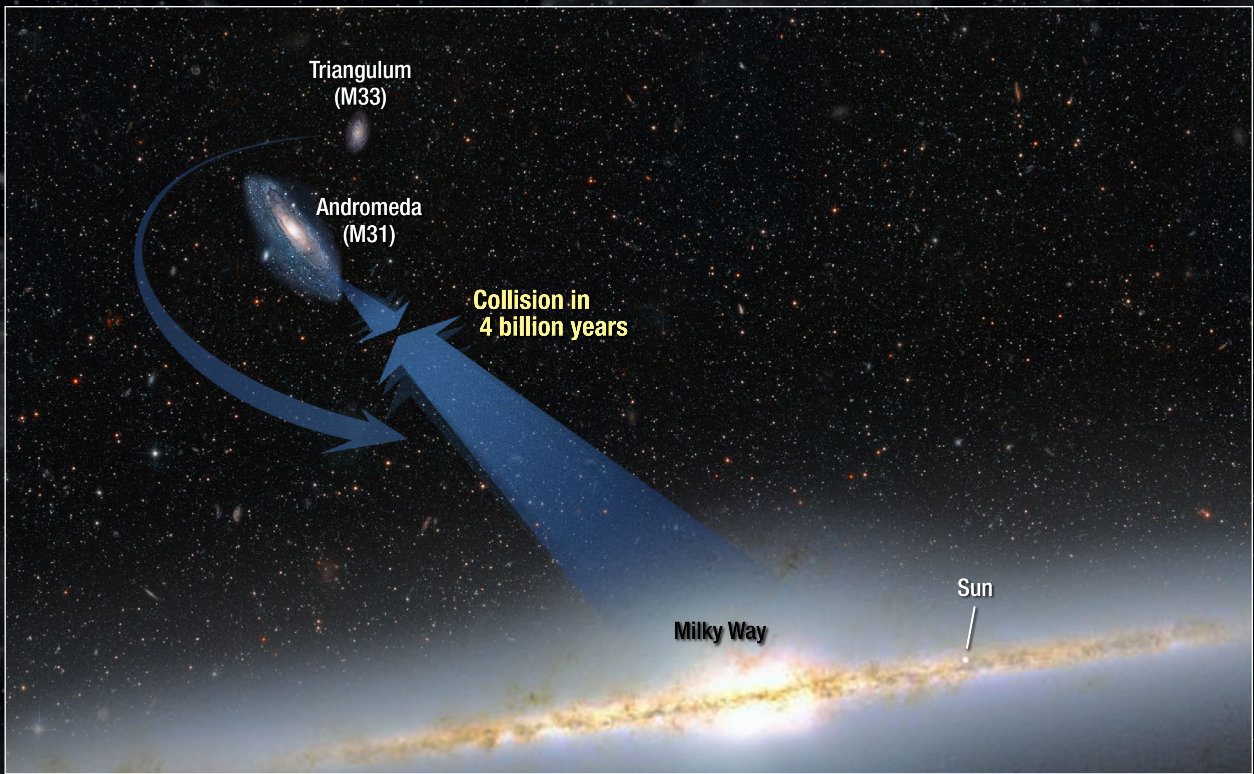
This photo illustration depicts the night sky in 3.75 billion years, as the Andromeda galaxy approaches. At this point, Andromeda fills the field of view, and the Milky Way begins to show distortion due to the tidal pull from Andromeda.

Destined for an Encounter

Hubble went on to discover a multitude of other galaxies in space, both spiral and elliptical in shape. He found that the universe is uniformly expanding, as evidenced by the movement of most galaxies away from our own. However, due to the strength of the gravitational attraction between the Andromeda and Milky Way galaxies, astronomers have long known that these two are destined for an encounter—despite the overall expansion of space. What has remained unknown, however, is whether this encounter will be a miss, glancing blow, or head-on collision. The answer depends on Andromeda's tangential, or lateral, motion to the Milky Way. Until now, astronomers have been unable to measure this motion in the sky; it was simply too small to detect with the available telescopes and processing techniques of the past.

Now, exactly 100 years after Slipher's important velocity measurement of M31, a team of astronomers led by Maryland-based astronomer Dr. Roeland van der Marel has, for the first time, measured the lateral motion of the Andromeda galaxy

This drawing depicts the inevitable collision between our Milky Way galaxy and the Andromeda galaxy approximately 4 billion years from now. The galaxies are moving toward each other under the inexorable pull of gravity between them. A smaller galaxy, M33 in Triangulum, may also be part of the encounter.

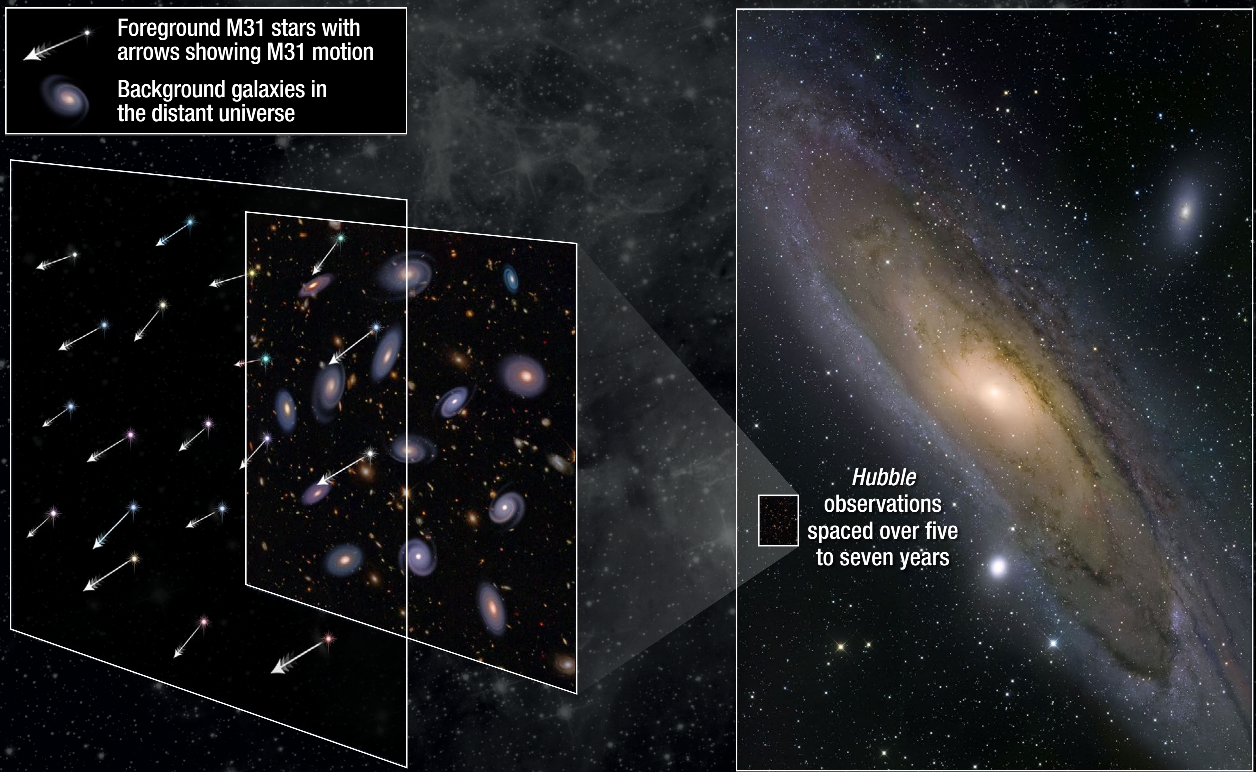


using *Hubble*. The measurements show that Andromeda's tangential velocity is well below its approach velocity; M31 and the Milky Way are headed directly toward one another. The galaxies will have a very close passage—or perhaps a direct hit—some 4 billion years from now. Astronomers believe the encounter will eventually result in the complete merger of the two systems into one, large elliptical galaxy some 6 billion years from now.

Measuring the Lateral Motion of Andromeda

Van der Marel and his team used *Hubble* to observe select regions of the Andromeda galaxy over a five- to seven-year period. They measured the galaxy's lateral motion by determining the displacement over time of thousands of M31's stars with respect to hundreds of distant background galaxies. What made this project so challenging is that the shift is extremely small—slightly less than one-hundredth of a pixel. Small as it is, by developing sophisticated data analysis techniques, they found this motion could be measured with confidence.

This illustration shows one of the regions in the neighboring Andromeda galaxy where astronomers aimed Hubble *to make precise measurements of the galaxy's tangential motion. As the galaxy drifts through space, the stars appear to move uniformly in one direction against the far more distant background galaxies, which remain fixed.*



This composite image shows a region in the halo of the neighboring Andromeda galaxy that astronomers used to measure the galaxy's sideways motion in the sky. The inset image on the left is from a 2002 Hubble *deep exposure that captured the light from 300,000 stars in Andromeda's halo, a vast spherical cloud of stars surrounding the galaxy's bright disc. Embedded in the image are numerous background galaxies that are much farther away than Andromeda. Astronomers compared this region with pictures of the same area taken seven years later. They measured the tiny amount of sideways drift in the halo stars relative to the stationary background galaxy field. Similar measurements were performed on two other fields in the galaxy.*

The researchers combined the results from different observed fields within M31. They then used a computer program that models how stars move inside the Andromeda galaxy and how they will appear to shift due to the Sun's own motion in the Milky Way. The model also included information on how other galaxies around Andromeda are moving.

Unprecedented in Our Galaxy's History

Although the universe is expanding and accelerating, collisions between large galaxies in close proximity, labeled *major mergers*, still occur because these galaxies are bound together by the gravity of their visible masses and the dark matter surrounding them. *Hubble*'s deep views of the universe show that such encounters were more common in the past when the universe was smaller.

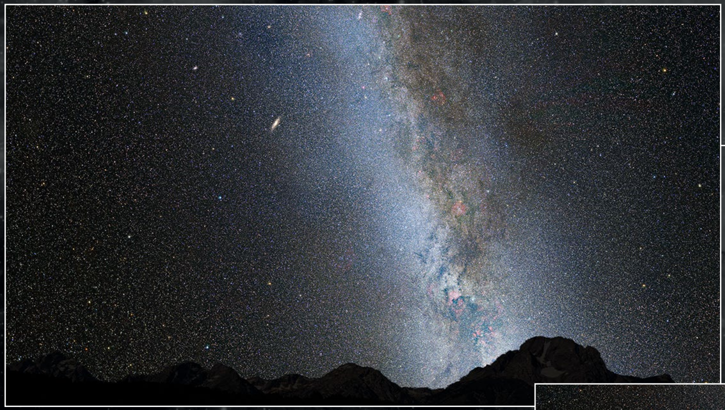
Astronomers know of other merging spiral galaxies, such as the remarkable collision between NGC 6050 and IC 1179. Together known as Arp 272, this pair is part of the Hercules galaxy cluster, some 450 million light-years from Earth. A third small galaxy, seen above the primary two, is also involved in this complex encounter.

Minor mergers, encounters between large galaxies and small satellite galaxies, are even more common. These, however, do not dramatically change the shape or classification of the large galaxies involved. The Milky Way has probably experienced many minor mergers over time, but this predicted merger with Andromeda is one of unprecedented scale during our galaxy's history.

Andromeda and the Milky Way are now approaching one another at 250,000 miles (402,336 kilometers) per hour. As they continue to draw closer, their speeds will increase. In time, both galaxies will distort due to the tidal pull of gravity, and some of their stars will be thrown into long, streamer-like tails. These features are commonly seen in other colliding galaxies.

As the merger progresses, both galaxies will drive their stellar populations into different orbits. In 6 billion to 7 billion years, the Milky Way will lose its flattened, pinwheel shape, taking on a more spherical structure characteristic of those galaxies called *ellipticals*. Many elliptical galaxies in the universe appear to have formed this way, as they are often found in the center of massive clusters of galaxies, where collisions and mergers are common.

Because galaxy mergers occur on such extremely long timescales, they cannot possibly be viewed as more than snapshots, even if observed across multiple generations. Instead, scientists rely on computer simulations that compress billions of years into a few seconds to visualize the contours of a galactic collision. Additionally, astronomers use observations of many different galactic mergers in the heavens to better identify and understand the various important stages of the overall merger process. The following seven illustrations, created from extensive computer modeling, present various stages in the merger of the Milky Way with M31.



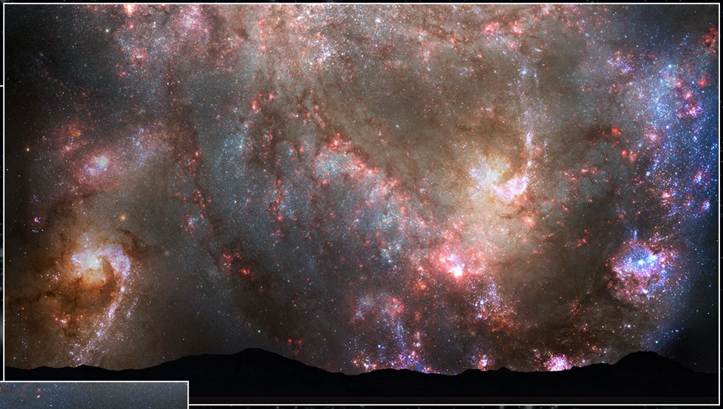
The Milky Way dominates this nighttime image with its bright belt. The Andromeda galaxy lies 2.5 million light-years away and looks like a faint, elongated disc with a bright center.

In 2 billion years, the disc of the approaching Andromeda galaxy will be noticeably larger and its spiral form clearly visible.

In 3.75 billion years, Andromeda will dominate the night sky, and the Milky Way will begin to show distortion due to the tidal pull from Andromeda.

During their first close approach, in 3.85 billion to 3.9 billion years, the night sky will blaze with new star formation, evident in a plethora of bright nebulas and young, blue star clusters.

New star formation continues at a vigorous rate throughout the closest approach.



In 4 billion years, after their first close passage, Andromeda and the Milky Way will be mutually stretched and warped by gravitational tides.

During their second close passage, in 5.1 billion years, the cores of the Milky Way and Andromeda will appear as a pair of bright lobes. Star-forming nebulas will be much less prominent because previous bursts of star formation will have decreased the amount of available interstellar gas and dust.

In 7 billion years, the merged galaxies will form a huge elliptical galaxy, its bright core dominating the nighttime sky. Once scoured of dust and gas, the new galaxy will no longer form stars unless minor mergers continue, and few, if any, nebulas will appear in the sky. The aging starry population will no longer be concentrated along the now-familiar Milky Way plane, but instead will fill an ellipsoidal volume.

The Fate of the Solar System

Most astronomers believe that the Sun was born approximately 4.5 billion years ago and has sufficient fuel to perform nuclear fusion for approximately another 6 billion years. When Andromeda and the Milky Way make their first pass in about 4 billion years, the Sun will still be a regular star with its planetary system as it is today.

Simulations show the collision will probably toss our solar system much farther from the galactic core than it is today, though Earth and the solar system are in no danger of being destroyed. Although the galaxies will plow into one other, stars inside each galaxy are so far apart that they will not collide with other stars during the encounter. Planetary systems, such as our solar system, in both galaxies will likely survive intact. However, the stars will be thrown into different orbits around the newly formed galactic center.

If our Sun is thrown into an elliptical orbit, it will be moving much faster through the dense inner galaxy for part of that orbit. This means that chance fly-bys with other stars will increase. The gravity from these stars may perturb comets on the outskirts of the solar system and cause them to fall toward the Sun and bombard the planets. However, about 5 billion to 6 billion years from now, the Sun itself will transition from fusing hydrogen to fusing helium and will swell into a red giant, likely engulfing the inner planets—including Earth.

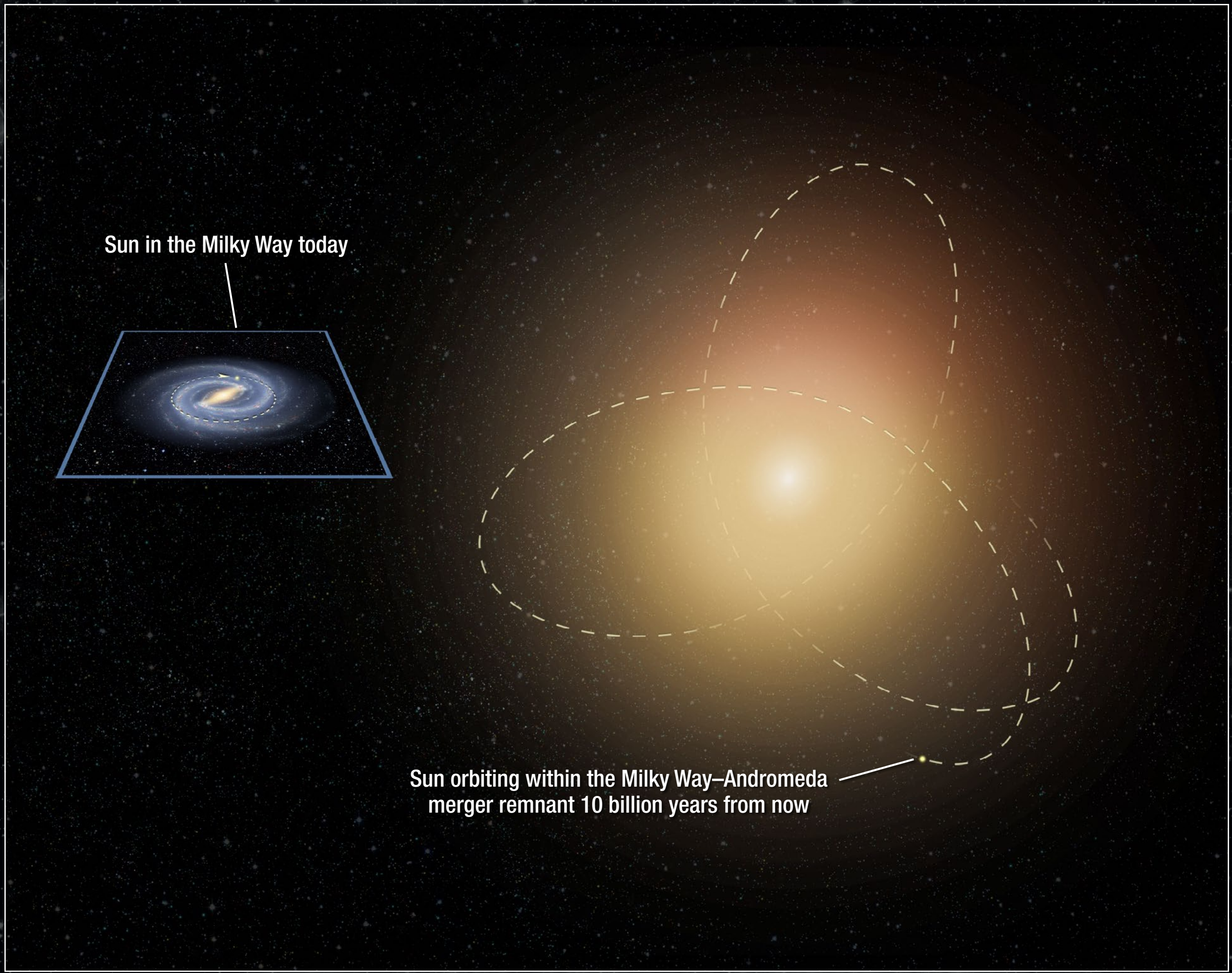
A New Black Hole

Both the Milky Way and Andromeda have supermassive black holes at their centers. After the galaxies collide, the black holes will merge over time to form one larger black hole. Models predict that this process will unleash bursts of gravitational waves as well as electromagnetic radiation.

Once the merger begins, gas will begin to flow toward the center of the merged galaxy, causing the region around the new black hole to heat and radiate brighter than its two individual progenitors currently do. However, it is unlikely that there will be enough gas in the new elliptical galaxy to fuel the black hole to the point of it becoming a quasar. Quasars produce prodigious amounts of energy beamed in opposite directions from high-velocity jets triggered in some mysterious fashion by gas spiraling into a supermassive black hole.

The Triangulum Galaxy: A Third Player

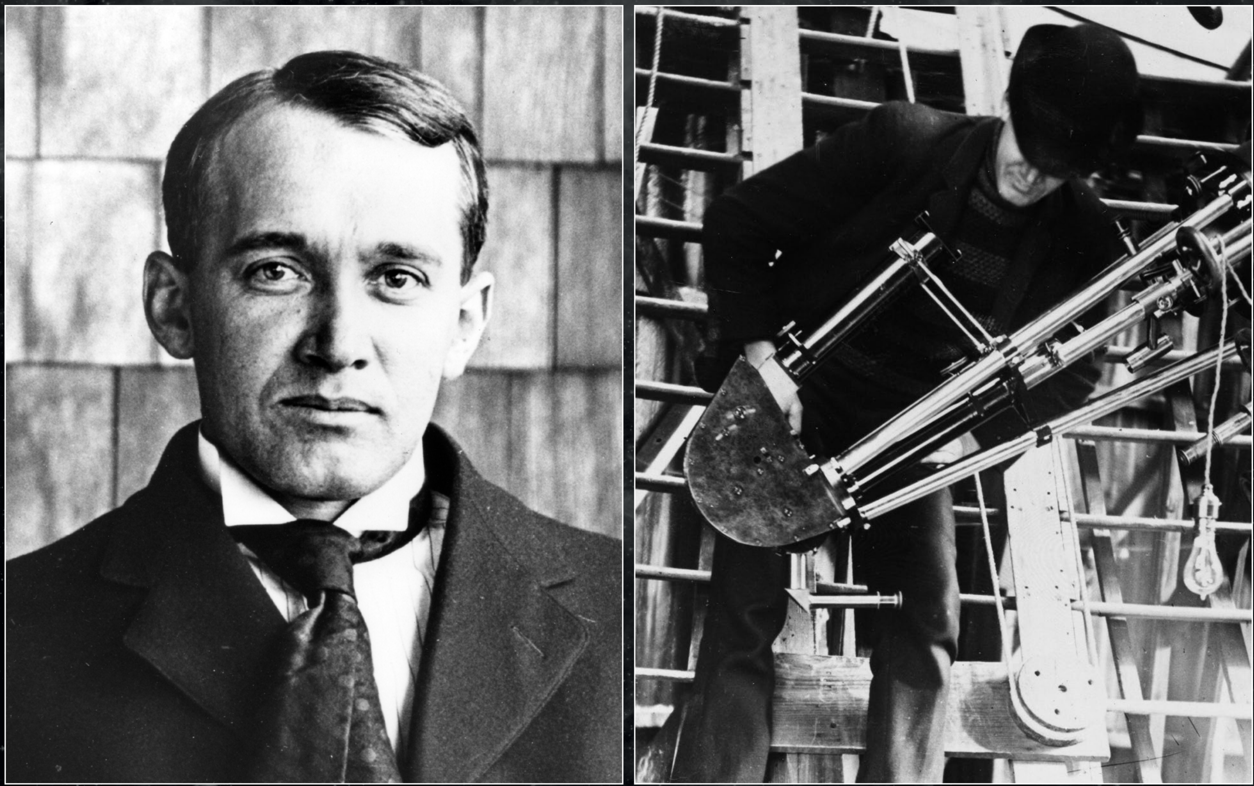
Dwarf galaxies that are closest to the collision will also have their orbits changed. Researchers believe this will be the case for M33, the Triangulum galaxy. Comprising approximately 10 percent of the mass in the Milky Way, M33 is the third most



This illustration compares the size of our galaxy at present to that of the elliptical galaxy predicted to form from the merger of the Milky Way with Andromeda. Our Sun now orbits in the Milky Way's disc. After the merger, it likely will be tossed into a looping orbit that will bring it both nearer to the center and farther into the outskirts of the newly formed galaxy.

massive galaxy in the Local Group. It is gravitationally bound to Andromeda and is, therefore, moving with Andromeda toward the Sun. Simulations predict that there is a good chance that Triangulum will survive the collision as a distinct entity and settle into an orbit around the Milky Way-Andromeda merger.

There is, however, a nine percent chance that Triangulum will make a direct hit on the Milky Way before Andromeda arrives, and a seven percent probability that it will be ejected out of the Local Group. There is even a small chance that the Sun will find itself inside the Triangulum galaxy at some time in the future. Even though, dynamically, it will still be part of the Milky



(Left) Vesto Slipher spent his career at Lowell Observatory in Arizona and used spectroscopic observations to determine the movement of galaxies. This work included determining the velocity of the object M31 (Andromeda), which at the time had not been identified as a galaxy. (Right) Slipher adjusts his custom-made instrumentation package on the 24-inch refracting telescope at the observatory. (Photo credit: AIP Emilio Segre Visual Archives)

Way-Andromeda merger remnant, the solar system may find itself temporarily moving through this third galaxy before falling back toward the center of the merger remnant.

Summary

Astronomers using *Hubble* data have now answered a question that has been asked by fellow scientists for the last 100 years—are the two largest galaxies in the Local Group destined to collide? The answer is "yes." Though separated by a vast expanse at present, during the course of the Sun's lifetime, the Milky Way and the Andromeda galaxies will meet and merge. Based on computer simulations, these two large spiral systems will likely form one huge elliptical galaxy. The merger will also affect smaller galaxies in the Local Group, like M33, the Triangulum galaxy, either by tossing them into new orbits or absorbing them all together.

In any case, several billion years from now, our distant descendants will behold a night sky that is markedly different from ours today. The bright lane of the Milky Way will be gone—replaced with stars, brilliant star clusters, and glowing nebulas in an indescribably magnificent display.

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Roeland van der Marel grew up in The Netherlands. There, he pursued a double major in astronomy and mathematics at Leiden University, where he also obtained a doctorate in astronomy. He worked for three years as a Hubble Fellow at the Institute for Advanced Study in Princeton before moving to the Space Telescope Science Institute in Baltimore in 1997, working first as an Institute Fellow and now as a tenured astronomer. He is also an adjunct professor in the Department of Physics and Astronomy at The Johns Hopkins University. Dr. van der Marel's current research focuses on black holes and the structure of galaxies.