Upcoming Astronomy-themed Talks and Events

Thursday, 2/27, 3:45-5:00pm Astronomy Colloquium – Phys-Astr A102 – Jessie Christiansen (CalTech) – “Ten Thousand Pieces of Blue Sky: Building towards the complete picture of exoplanet demographic”.

We focused our attention last time on one of the greatest of all mysteries – how common is intelligent life in the Galaxy?

As we discover more and more planets around other stars, will we find them empty, or teeming with alien civilizations?

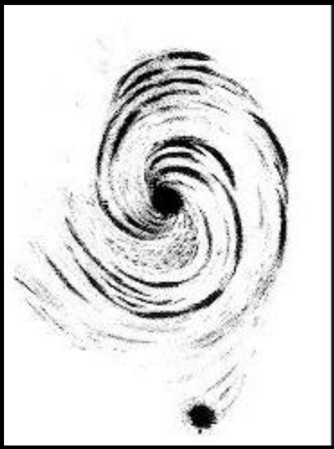
We argued that some major parts of this question are becoming increasingly clear, and within the first few decades of this century we may know with some certainty how likely it is that life – if not ***intelligent*** life – will arise on a given planet.

But let's turn our attention now to another mystery, one that was only solved in the first few decades of the ***last*** century…

The Mystery of the "Spiral Nebulae"

Around the 1920's, while astronomers like Harlow Shapley were working out the shape and size of our own galaxy, a great deal of attention was also being paid to some strange objects that had puzzled astronomers for hundreds of years. What, they asked, were the faint, fuzzy, spiral patterns seen in many spots in the night sky?

Photographs of spiral nebulae, ca. 1920.



Many, like Shapley himself, argued that these were nearby stars in the process of forming, and that the spiral disks were composed of gas, dust – and maybe forming planetary systems.

Other astronomers, however, suggested that the spiral nebulae were distant 'island universes' of billions of stars, like our own Milky Way, but much more distant and outside of our Galaxy.

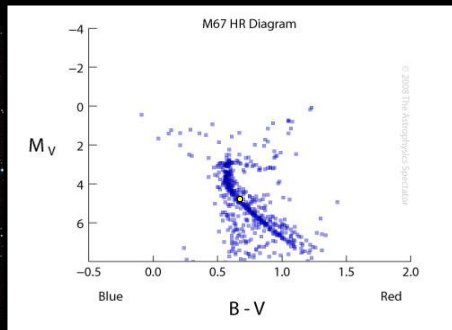
How do you tell which of these ideas is right? The only definitive way would be to find reliable distances to the spiral nebulae themselves – but they were all too far away to show any kind of ***parallax***.

How then could the distances to these objects be determined?

How to Measure Very Large Distances – Standard Candles

Any astronomical object whose luminosity can be determined *without* knowledge of its distance is called a **standard candle**. Since we know its luminosity, we can calculate the distance to a standard candle by measuring its apparent brightness, and then using the luminosity-distance formula:

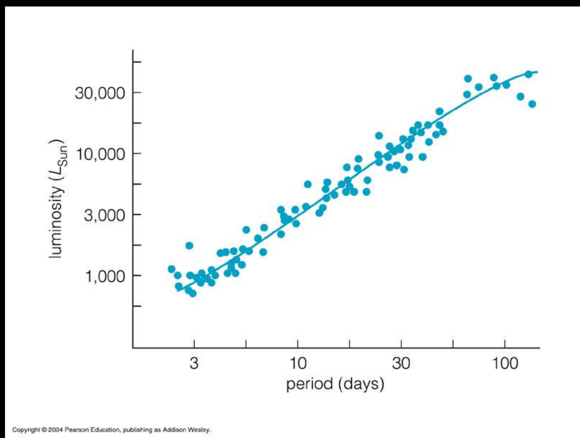
$$\text{Apparent Brightness} = \text{Luminosity}/(4\pi\text{Distance}^2)$$



For example, main sequence stars can be used as standard candles. If we see a star with the same spectral type as the Sun, we can assume that it's the same kind of star as the Sun, and that its luminosity basically equals the Sun's. Using that luminosity, we can then calculate the distance to that star – as in the case of solar type stars in the open cluster M67 (above)!

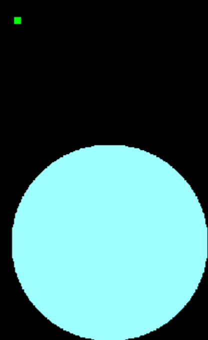
But there are better standard candles available – so-called Cepheid Variables, which are a class of hot (Spectral Type F – G), bright Giants that pulsate over periods of 1-100 days. Because they get bigger and smaller, they get brighter and dimmer to a noticeable degree.

Cepheid variable in M31 (top); artist's impression of a Cepheid pulsating (bottom).

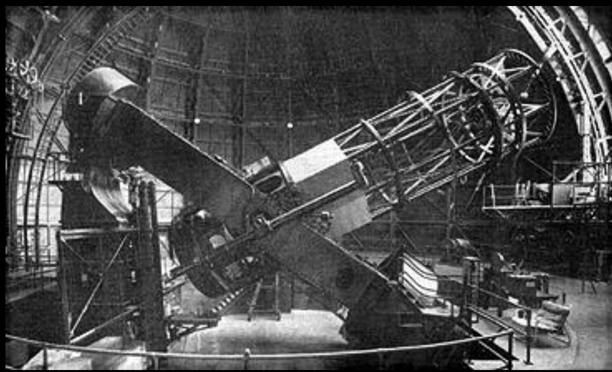


Research in the early 1910s by Henrietta Leavitt and others showed that the pulsation periods of Cepheid variables are longer for stars of higher absolute brightness – that is, intrinsically ***brighter*** Cepheid variables take ***longer*** to pulsate.

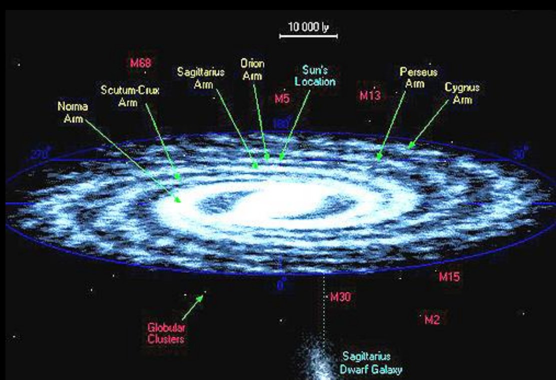
Because they show a clear relationship between the timing of their pulsations and their true luminosity, Cepheid variables make great standard candles. Just measure a Cepheid's pulsation period (which is easy to do!), estimate its luminosity, and combine that with its apparent brightness to get its distance as well!



Animation of the pulsations of a Cepheid variable star – the green line shows measurements of the star's total brightness as time passes.

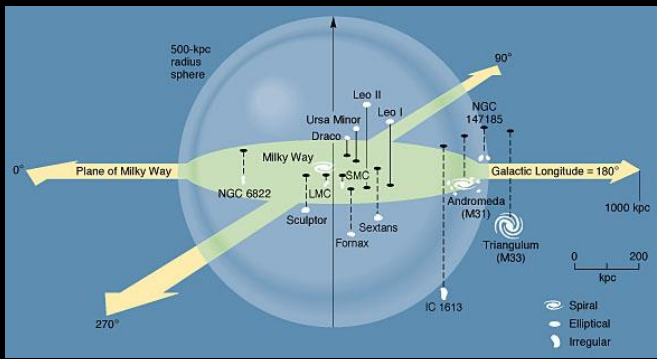


In the early 1920’s, Edwin Hubble used the newly constructed 100 inch telescope at Mt. Palomar to discover Cepheid variables in what was then known as the *Andromeda nebula*. He used them to estimate a distance to Andromeda of over 2 million light years from Earth – and far outside of the Milky Way!



A ‘map’ of the Milky Way – or as we used to call it, “the Universe”!

Note what this did to the very concept of our Universe at that time! Before this work in the mid-1920s, the majority of astronomers believed that the Milky Way galaxy represented all of the stars in the Universe. This meant that the ***Universe*** as we knew it was only a few hundred thousand light years across!



The Local Group of Galaxies, some 4.5 million light years across – and this is really just scratching the surface…

The discovery of galaxies outside of the Milky Way showed us that the Universe is FAR larger than that – many billions of light years larger! How deep does this rabbit hole go?

Very Deep

In 1995 – as part of what was at first a 'side' project – the Hubble Space Telescope observed a tiny, apparently empty patch of sky in the Big Dipper for a total of 10 solid days.

By counting the Galaxies in this tiny patch, we can estimate that there are over 100 billion galaxies in the observable Universe – each with hundreds of billions of stars!

How does one even begin to study such remarkably distant and diverse things?

Astronomers immediately began to classify these galaxies into three major types: ***Spiral***, ***Elliptical***, and ***Irregular*** – a system originally proposed by Hubble.

The sizes of all three types of galaxies span a wide range, from ***dwarf*** galaxies containing less than 100 million (10^8) stars or so (like big globular clusters!), to ***giant*** galaxies containing over 1 trillion (10^{12}) stars!

Spiral Galaxies

- have a *disk component* along with a bulge and halo (*spheroidal components*)
- the disk contains large quantities of gas and dust (ISM)
- the relative sizes of the bulge and disk and the amount of ISM varies among spiral galaxies
- they contain significant numbers of both blue & red stars

Elliptical Galaxies

- only have a *spheroidal component;* no *disk component*
- they contain very little ISM, and what they do have is mostly very low-density and very hot (not good for star formation!)
- they appear red because they contain mostly red stars

Irregular Galaxies

Historically, this is the “none of the above” category – neither spiral nor elliptical.

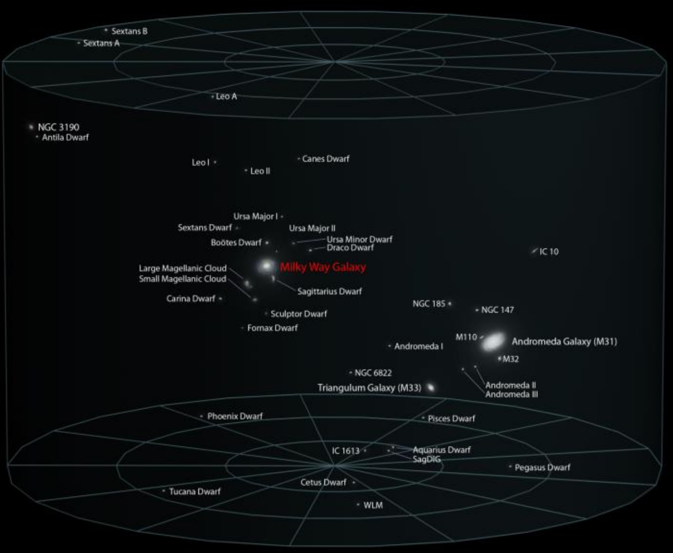
They appear white & dusty with a rich ISM – much like the disk component of spirals.

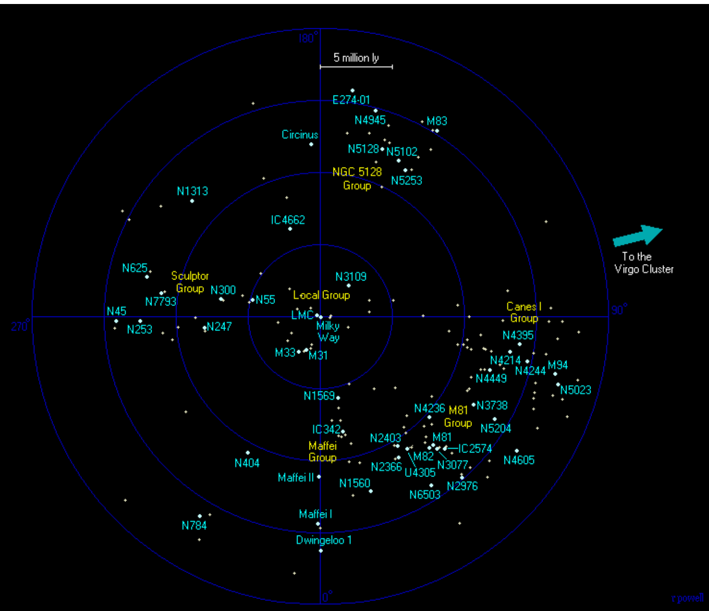
Galaxies are found in “Groups” and “Clusters”

Many galaxies are found in loose ***groups*** containing dozens of galaxies. These include elliptical and irregular galaxies, as well as most of the largest spiral galaxies. Our Local Group is an example of such a group, with roughly 30 galaxies in it, dominated by two large spirals: the Milky Way, and the Andromeda galaxy.

HCG 87 – A Group of Galaxies

Local Galactic Group

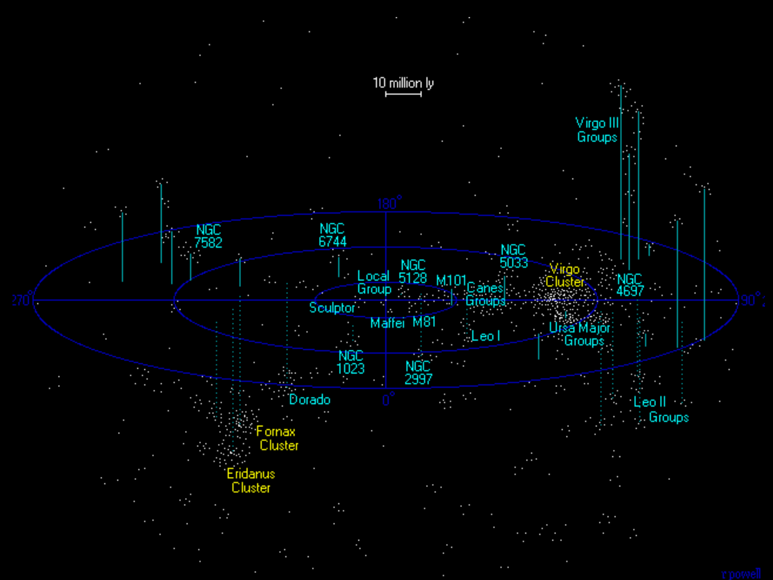




A map of the nearest few groups of galaxies.

Many more galaxies associate in tightly bound *clusters*, containing many hundreds of galaxies.

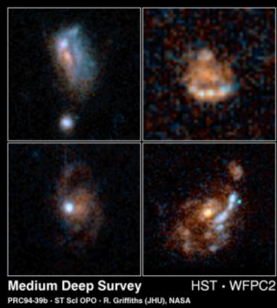
Within those clusters, more than half of the large galaxies are elliptical, while outside of clusters such large ellipticals are rare (~15%).



A map showing the nearest large clusters of galaxies.

How do galaxies form and evolve? How does their environment shape them? In order to answer these questions we must understand how galaxies change over time – and that means we need away a way to estimate the ***ages*** of galaxies.

This task is made a little easier by the observed fact that all galaxies appear to have formed within a few billion years of each other, in the very early Universe some 12-13.5 billion years ago. So for practical purposes, we can assume that all galaxies we can observe formed at basically the same time.

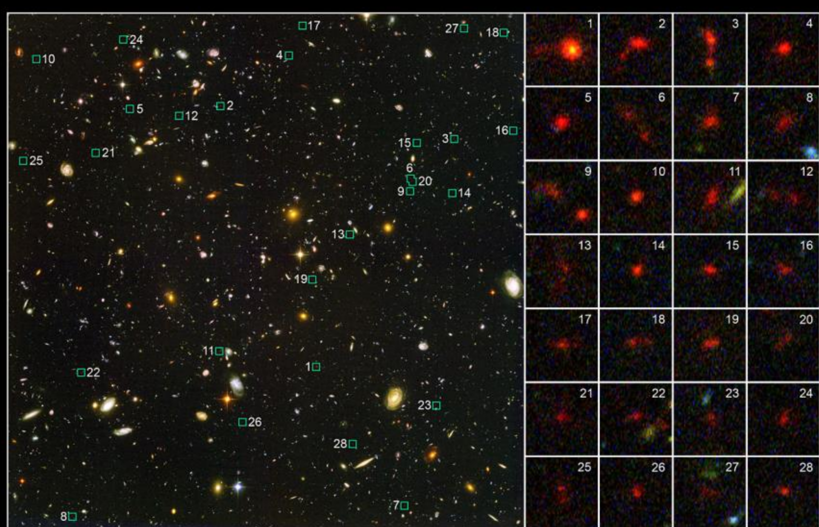


The next step is to consider the ***distance*** to the galaxy – because light travels at a finite speed, when we observe a galaxy that's, for example, 10 billion light years away, we must be seeing it as it was 10 billion years ago, when it was 10 billion years "younger" than it is 'now'! But when we look at the nearby Andromeda galaxy, we are seeing it as it was only 2.5 million years ago – over 12 billion years since the time of its formation.

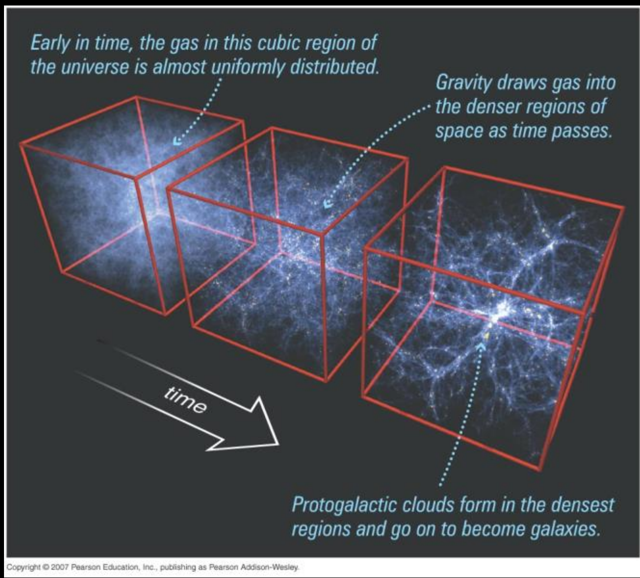
For example, this image shows a nearby spiral galaxy, with a more distant cluster of galaxies in the background. Which galaxies appear 'younger' in this photo? Which are we seeing 'later' in universal history, and which ones are we seeing 'earlier'?

~12 billion year old galaxies ~8 billion year old galaxies ~1 billion year old galaxies

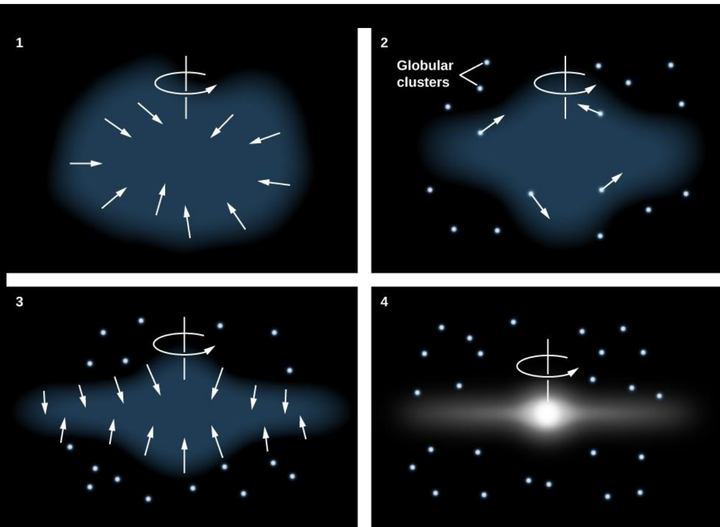
So by comparing galaxies of varying ***distances***, we are actually comparing galaxies of various ***ages***. This allows us to develop an understanding of how galaxies form and change over time.



Here are images of 28 young galaxies in a field observed by the HST – note how tricky this work is!

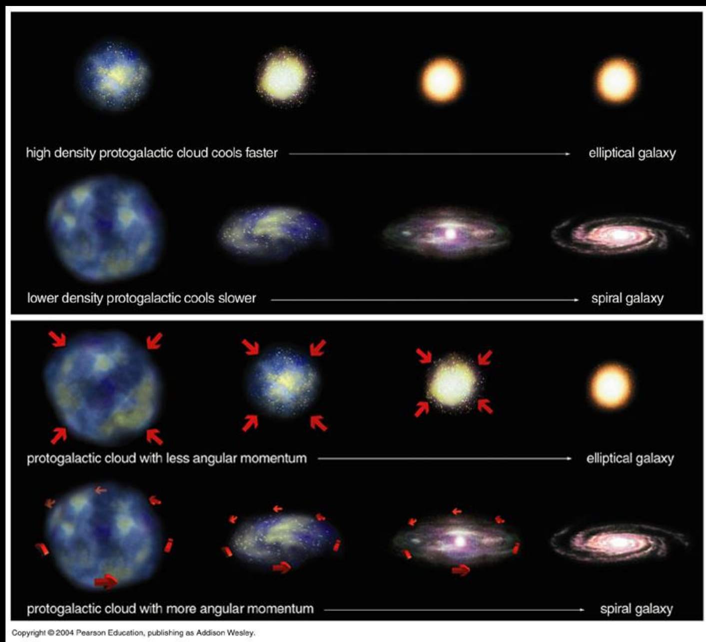


Evidence from these studies suggest that galaxies appear to have started forming some 12-13 billion years ago, from vast clouds of almost pure hydrogen and helium gas.

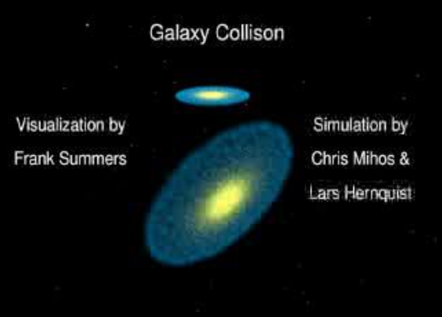


Some of the evidence supports a so-called "top-down" model of galaxy formation, by which we believe many proto-galaxies form.

The initial density and angular momentum of those forming galaxies affects their shape and content...



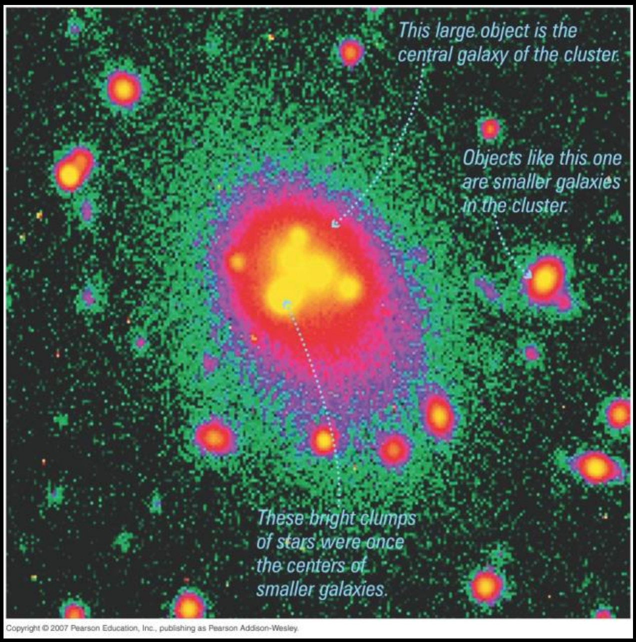
…as does violent processes like supernova explosions, and radiation from the supermassive black holes also forming in those galaxies. Models suggest these can radically alter the content and shape of galaxies as they evolve, stripping away gas from the galaxy and limiting later star formation.



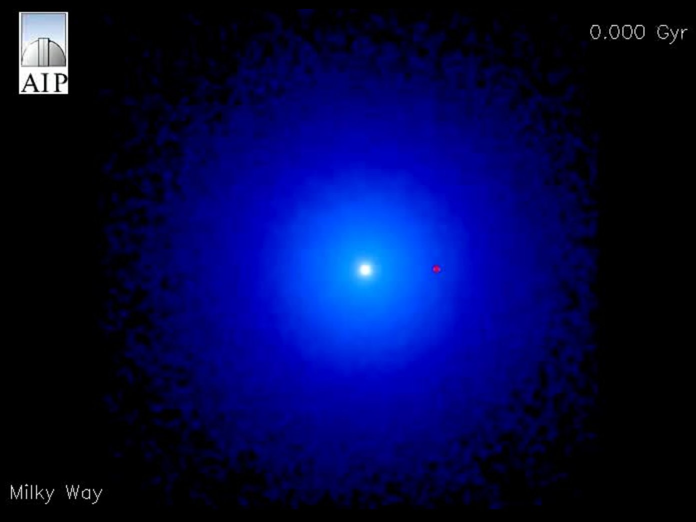
However, ***collisions*** between galaxies play a very significant role in their formation and evolution. This is because galaxies – relative to their sizes – are fairly closely packed together, much more so than stars or planets. This means they "interact" with each other much more commonly that do individual stars inside of galaxies.

Distorted and apparently interacting galaxies are noticeably common in dense clusters – as are elliptical galaxies, and in particular giant elliptical galaxies.

This suggests that the largest elliptical galaxies may likely form through multiple mergers with other galaxies.

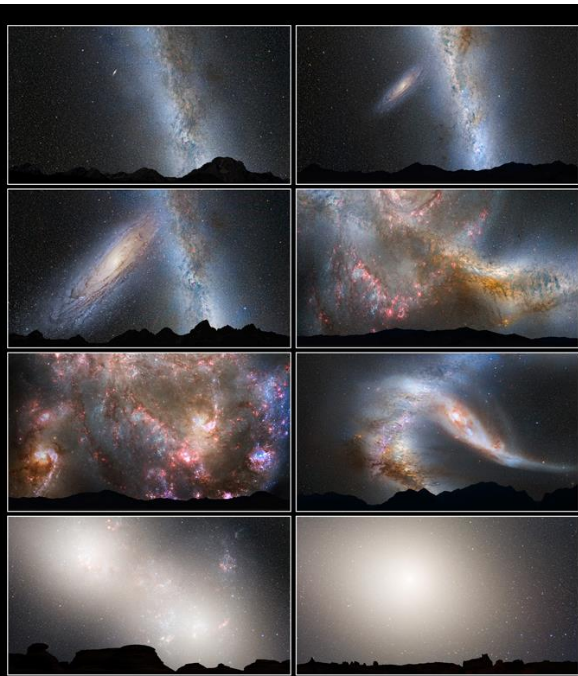


And as we have noted before, the Milky Way will collide with the Andromeda Galaxy a few billion years from now! What an awesome sight that will be!



A look ahead at our Milky Way’s future!

Today…



…7 billion years from now!