Galaxies

CESAR's Booklet

What is a galaxy?

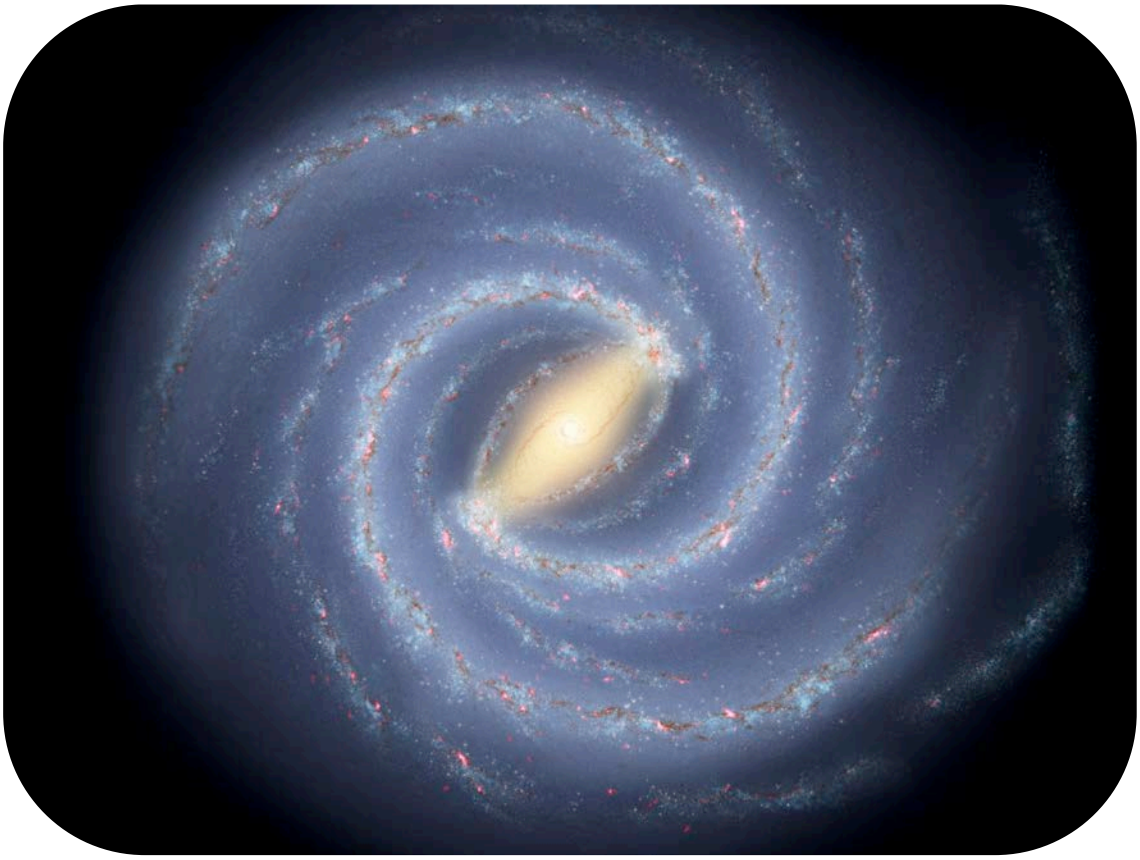

Figure 1: *A typical galaxy: our Milky Way (artist's impression). (Credit: NASA)*

A *galaxy* is a huge collection of stars and interstellar matter isolated in space and bound together by gravity. There are thought to be over 100 billion galaxies in the Universe, mainly residing in clusters and groups. The most well known galaxy is our own Milky Way –and indeed, the term *galaxy* comes from the Greek word 'gala', which means 'milk'.

Most galaxies have a total mass between 10,000 and 10 trillion solar masses, and sizes between a few to over several hundred kiloparsecs (1 kpc = $3.086 \cdot 10^{16}$ km). The Milky Way (shown in Figure 1) contains over 100 billion stars, including the Sun, and the stellar disk extends to about 30 kpc in diameter; it also has a stellar halo with a diameter of about 100 kpc, and a dark matter halo that may extend well beyond this.

Types of galaxies

The Hubble Tuning Fork

Galaxies are classified according to their shapes in optical (visible-light) images. The most common classification scheme in use today is the Hubble classification scheme, or *Hubble tuning fork* (Figure 2). In this scheme, galaxies are classified into the following broad categories: ellipticals, spirals, and irregulars. The ellipticals are smooth and round or elliptical, the spirals are flat with a spiral pattern in their disk, and the irregulars have stars and gas in random patches. Spirals are further classified into two types: regular spirals, where the arms come right out of the galaxy centre, or *barred* spirals, with the arms starting from the ends of a bar of gas and stars going through the centre. The ellipticals are sub-divided by how round they are and the spirals are sub-divided by how loose their arms are and how big their bulge is.

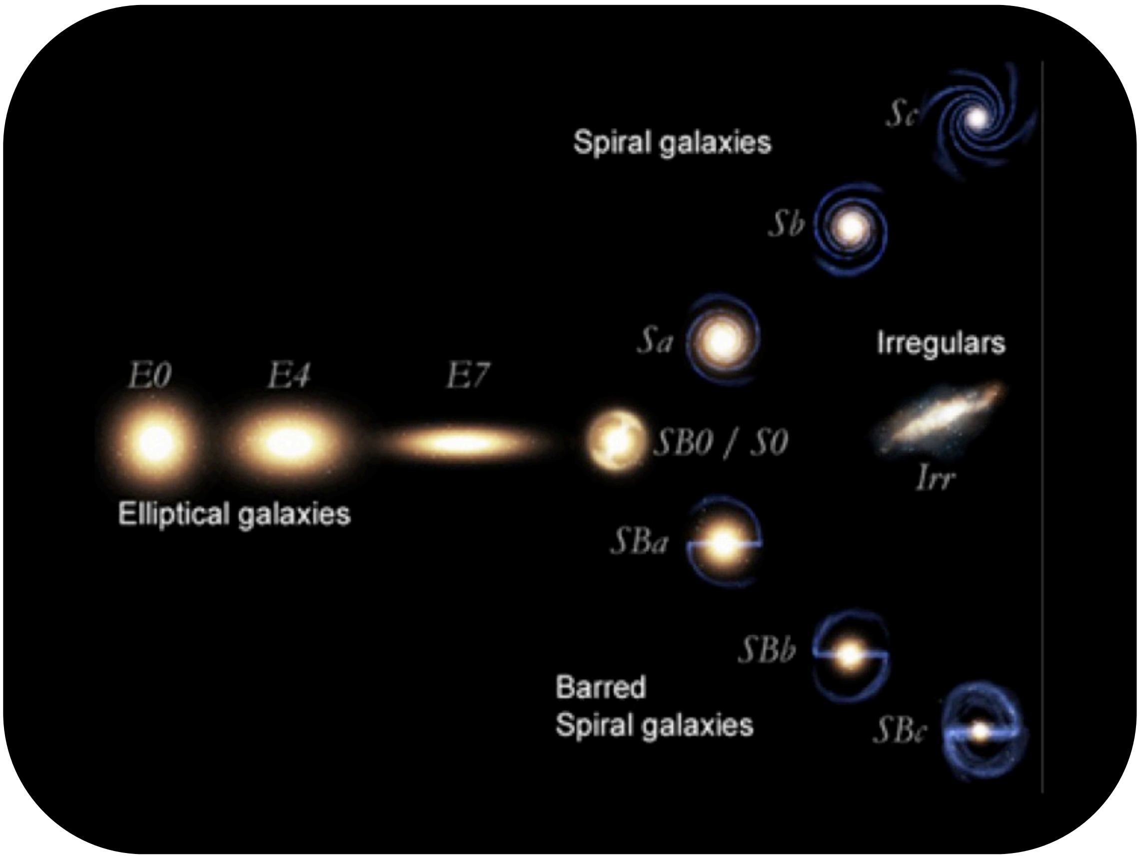

Figure 2: *The Hubble Tuning Fork. (Credit: NASA/ESA)*

In 1936, Hubble put these groups onto a two-pronged sequence that looks like a tuning fork, because he thought that the galaxies started out as ellipticals, then changed either to regular spirals or barred spirals, and then to irregulars. However, astronomers now know that this diagram does not represent the evolution of galaxies.

Parts of a spiral galaxy

Contrary to ellipticals and irregulars that show no clear structure, spiral and barred spiral galaxies have three clearly differentiated parts:

- The central part is called the *bulge* and contains de galaxy's *nucleus*, which is in most (if not all) cases a supermassive black hole that the rest of components of the galaxy orbit around. The bulge is spherical in normal spirals, while in barred spirals it appears elongated, with a *bar* connecting to the spiral arms.
- The bulge is surrounded by a flattened structure called the *disk*, which contains the *spiral arms*. Although stars in the arms are brighter, allowing us to recognise the spiral pattern, the regions between the arms are also filled with stars.
- The *halo* surrounds the bulge and the disk. It has a spherical shape and is subdivided into a smaller *stellar halo* containing lots of *globular clusters* (very big and dense groups of sibling stars with a spherical shape) and a larger *dark matter halo* wrapping the whole galaxy. As a matter of fact, it is thought that every galaxy, of every type, is surrounded by a dark matter halo, but the nature of this dark matter –called like this because it does not emit light, in any frequency– is so far unknown.

Figure 3: *Parts of a spiral galaxy. (Credit: Pearson Education)*

The sizes of galaxies

Most galaxies are small and faint and are called *dwarf galaxies*; they tend to be elliptical or irregular in shape. Only the most luminous and biggest galaxies are seen at great distances; these spectacular *giant galaxies* are always ellipticals. Spirals have intermediate sizes: they are bigger than dwarf ellipticals and irregulars, but smaller than giant ellipticals.

Figures 4 and 5 give an idea of the variety of sizes of galaxies as compared with our own galaxy, the Milky Way.

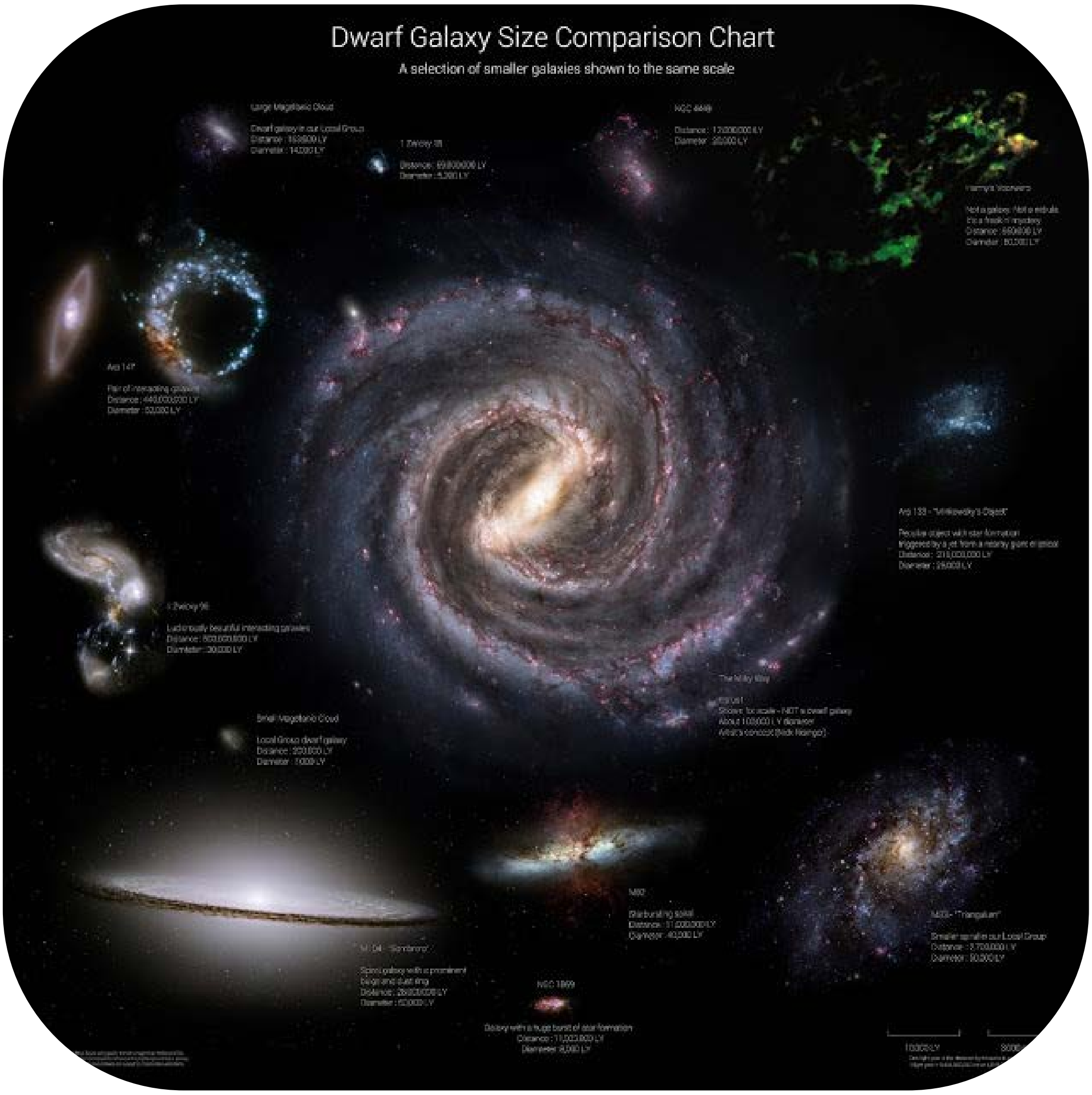

Figure 4: *Comparison of sizes of dwarf galaxies with the Milky Way. (Credit: rhysy.net)*

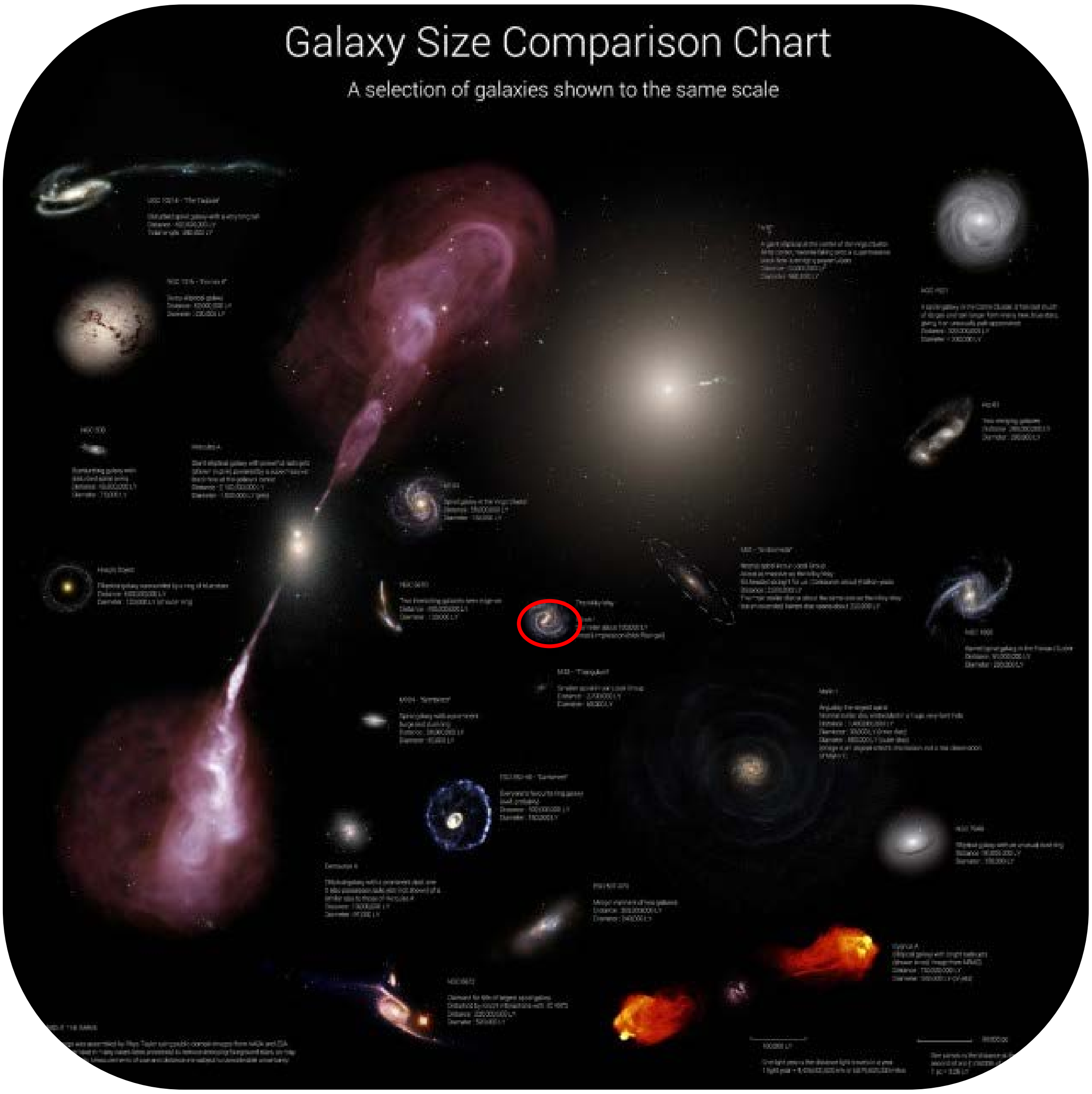

***Figure 5:** Comparison of sizes of a selection of galaxies with the Milky Way (encircled). (Credit: rhysy.net)*

The largest galaxy known is called IC 1101. This is an elliptical galaxy whose diameter is estimated to be approximately 1.7 Mpc. Compare this value with the 30 kpc diameter of the Milky Way! IC 1101 is found at the centre of a rich galaxy cluster, and probably grew in size by eating smaller galaxies.

The colours of galaxies

The optical colours of galaxies vary depending on their types: Elliptical galaxies usually show yellowish or reddish colours, in contrast with spirals and irregulars that tend to look more bluish. Inside a spiral galaxy, the central part or *bulge* looks yellowish or reddish, while the *disk* containing the spiral arms usually glow bluish; spirals are also surrounded by a *halo* of yellowish or reddish stars, often packed in spherical *globular clusters* (see Figure 3). Astronomers relate these colour differences to the different types of stars galaxies contain: Remember that stars get reddish when they evolve off the main sequence, while young massive stars are blue. Thus, if a galaxy looks bluish, it means that it contains lots of young stars, while a yellowish or reddish galaxy will contain mostly old stars. (Note that big, massive stars are the only ones bright enough to be observed at the distances of most galaxies.)

Since stars form from clouds of dust and gas, if a galaxy is rich in young stars, we expect it to contain large amounts of interstellar gas and dust as well; while a galaxy that does not contain much gas and dust will not have many young stars, as there is no material from which these stars can form. Therefore, we do not expect elliptical galaxies to be rich in gas and dust, and hence, they will not look very bright in infrared and radio images (as they mainly show the emission of dust and gas, respectively). On the other hand, galaxies rich in young stars, like spirals, must be very prominent in the infrared and radio.

Stellar populations

In the 1940s, German astronomer Walter Baade was able to resolve and study the stars in several nearby spiral galaxies. He noticed that they could be assigned to two main groups:

- *Population I:* Stars in this group are relatively young and have chemical composition similar to our Sun. They are said to be *metal-rich* because of their relatively high content of elements other than hydrogen and helium (called *metals* in Astronomy). These stars are located in the disks of spiral galaxies, moving in nearly coplanar, nearly circular orbits around the galactic centre.
- *Population II:* Stars in this group are older than Population II. They are *metal-poor*, meaning that their chemical composition is almost only hydrogen and helium, with very little traces of other elements. These stars are common in the bulges and halos of spiral galaxies, and move in randomly orientated, highly eccentrical orbits around the galactic centre.

Galaxy formation and evolution

Galaxy formation

Astronomers are just beginning to understand how galaxies form and evolve. They now think that all galaxies began forming about 13 billion years ago, when the Universe was very young. In the beginning, there were only very small clumps of stars and gas about the size of a million solar masses (the size of a globular cluster) that started collapsing, forming larger structures. Then galaxies would be drawn into clusters and superclusters by their mutual gravitational attraction.

This theory is supported by the fact that there are many more dwarf galaxies than giant galaxies; they may have originated from cloud fragments that did not get incorporated into larger galaxies. In addition, at very large distances, most galaxies are small and irregular; since the further we observe, the earlier in time (because light takes time to travel from the source galaxy to us), this means that early in the history of the universe, only small, irregular galaxies existed, as the ones shown in Figure 6.

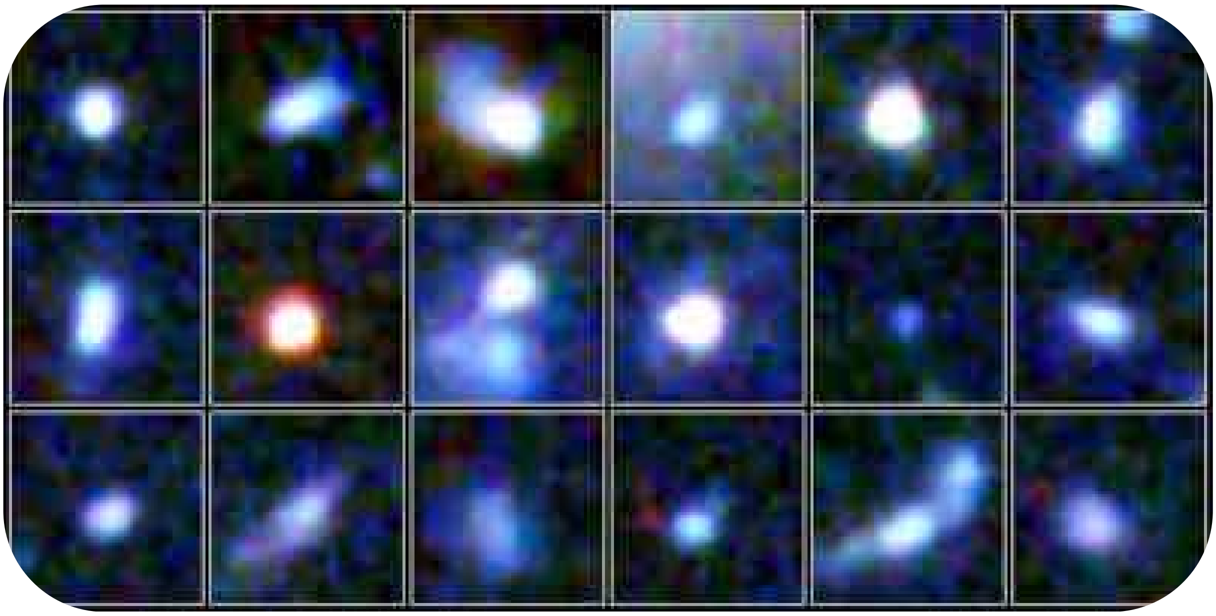

Figure 6: *Small, irregular galaxies like the ones in these images from the Hubble Space Telescope are observed at large distances. They are thought to be the 'building blocks' of current giant galaxies. (Credit: NASA/ESA)*

Another fact supporting this theory of galaxy formation and evolution is that collisions and mergers of galaxies are still observed today.

Interacting galaxies

The distances between galaxies are large, but not extremely large compared to their sizes: only a few times bigger. Thus galaxy collisions do happen quite often. The shapes of galaxies may get remarkably distorted in the collision, as in the example shown in Figure 7. The two galaxies can even merge to form a larger galaxy. The giant elliptical galaxies usually found close to the centres of galaxy clusters most likely formed from the collision and merging of smaller galaxies.

Stars inside a galaxy do not collide because the distances between them are hundreds of thousands to millions of times larger than the sizes of stars; for the same reason, when two galaxies collide, the stars will pass right on by each other without colliding, although their orbits can be radically changed.

On the contrary, the gas clouds in galaxies are much larger than stars, so they will likely hit the clouds in another galaxy when the galaxies collide. As a consequence, the clouds compress and collapse to form a lot of stars in a short time. Galaxies undergoing such a process are called *starburst galaxies.*

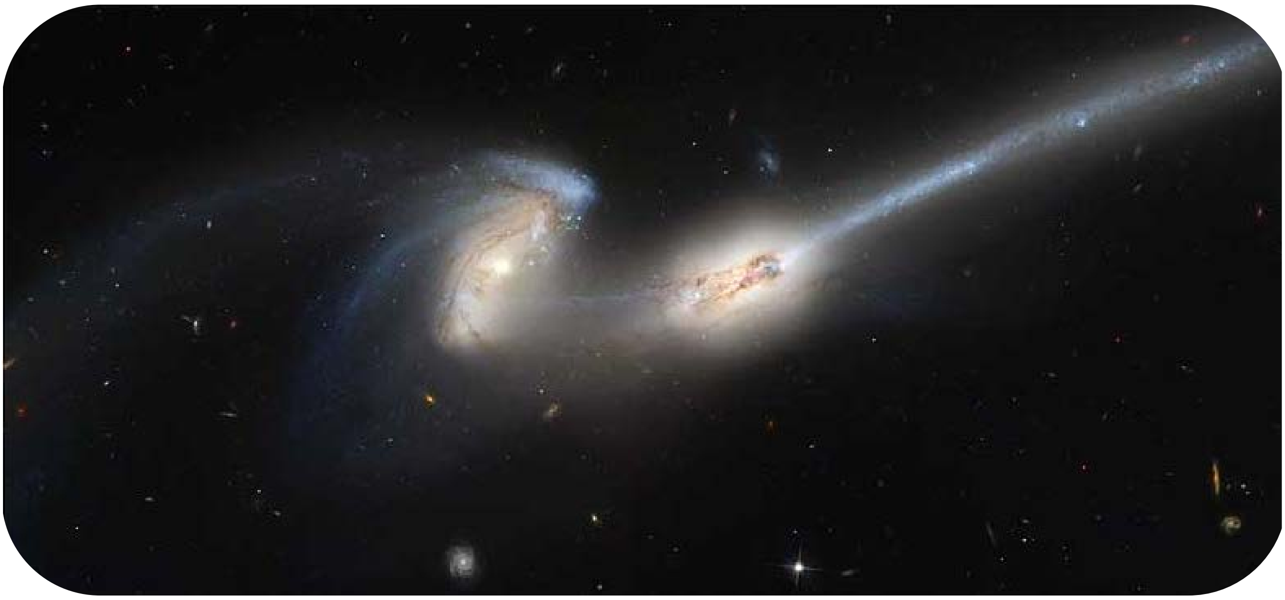

Figure 7: *The Mice, two colliding galaxies, as observed by the Hubble Space Telescope. (Credit: NASA/ESA)*

References

- *Astronomy Notes* by N. Strobel: http://www.astronomynotes.com
- *Cosmos, the SAO Encyclopedia for Astronomy*: http://astronomy.swin.edu.au/cosmos/

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