The Universe of Galaxies

Galaxies are magical objects made of stars. We live in a galaxy, the Milky Way galaxy to be specific, just like we live in a house or in a country. I am trying to stress the abstract nature of these "objects" where "made of" takes a completely different meaning. Lets try to flesh this out a little. At night when you look outside, if you are lucky to be living away from the bright lights of the cities, you see millions of stars (actually at a time you can see only a few thousand stars, but it does seem like millions, does it not?). The only galaxy you see is our own galaxy* in the form of a diffuse belt of stars - we are looking at the disk of our galaxy. If you stretch your eyes a little bit, there are a few nebulous, cottony objects that you can see. Originally it was thought that all of these are part of our own galaxy (written with a capital G - Galaxy). When spectra were obtained it was seen that most of these nebulae were moving away from us at several hundred km per second - clearly they could not be in the Galaxy. This and the discovery of the "standard candles", Cepheids (we will see more about these later) in these established that these were galaxies in their own right. All this happened only a few decades ago.

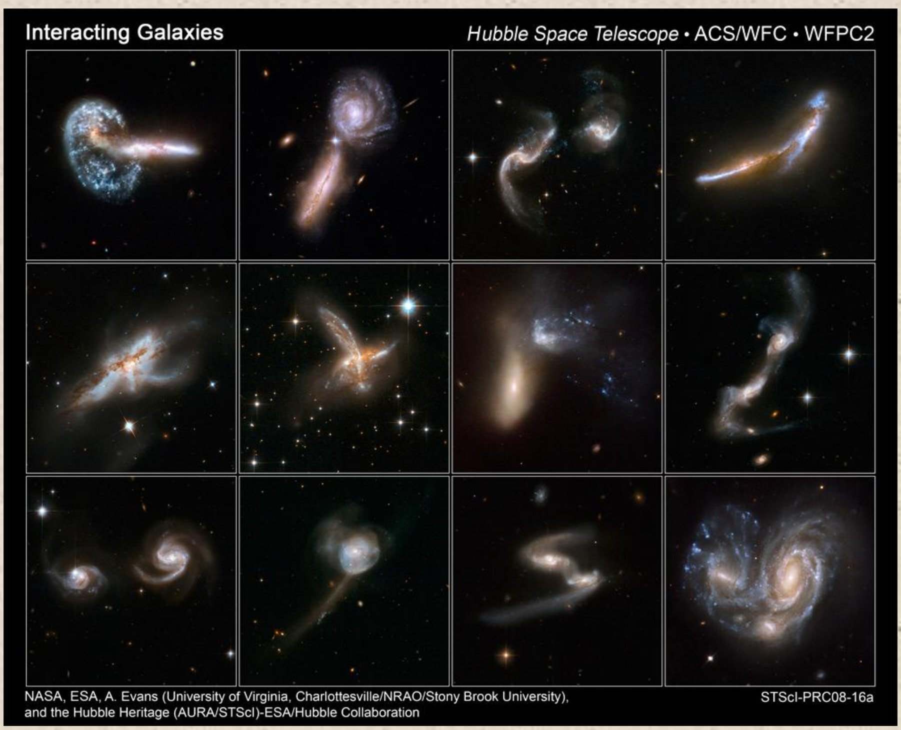

Fig. 1: A sampling of interacting galaxies
Credit:www.nasa.gov/mission_pages/hubble/science/hst_img_20080424.html

Now we know much better. For instance, a typical galaxy contains hundreds of billions of stars. Interestingly, the stars inside galaxies are so sparsely distributed (inter-stellar distances are millions of times the stellar diameters) that most of the galaxy is really empty. Compared to this, the inter-galactic distances are only a few times the diameters of galaxies. Indeed, it is fairly common for galaxies to collide with each other giving rise to streams of stars pulled out from both galaxies and distorting the shapes (see Fig. 1). When galaxies do collide, because of the large inter-stellar distances, the stars in the two galaxies do not collide, and the galaxies can pass through each other. Galaxies are generally found in groups of different sizes. The Milky Way Galaxy, for instance, is part of the rather imaginatively named "Local group" containing a few tens of galaxies. The entire Local group is "falling towards" the Virgo cluster (a cluster of hundreds of galaxies in the direction of the constellation Virgo). An example of a much larger cluster is the Coma cluster with thousands of galaxies.

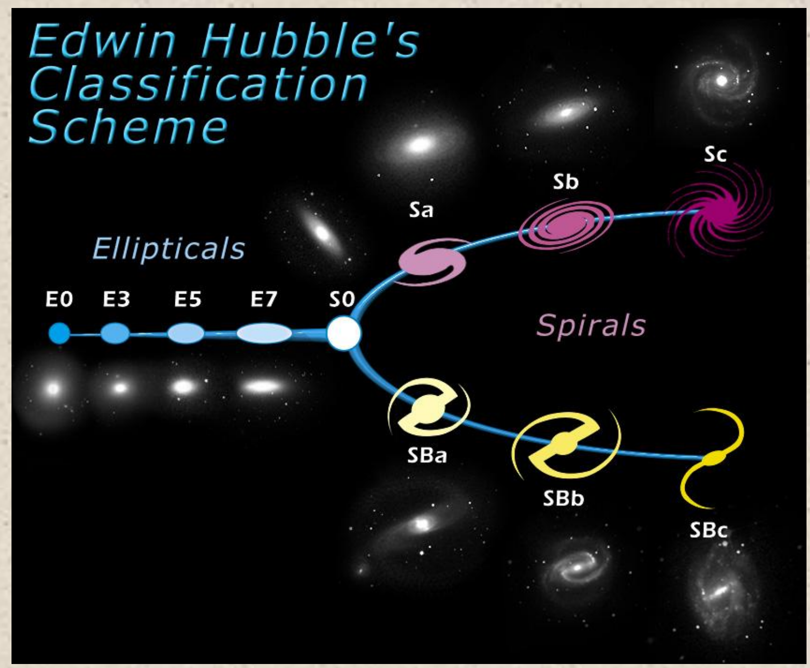

Fig 2: The Tuning Fork diagram, a simplistic galaxy classification scheme.
Credit: http://cas.sdss.org/dr6/en/proj/advanced/galaxies/tuningfork.asp

Broadly galaxies can be classified in to spirals and ellipticals. In addition to these there are dwarf galaxies and irregulars. Spirals may or may not have a central bar (an oblong structure). The Hubble classification diagram (see Fig. 2) is a simplistic view of galaxy types. The elliptical galaxies are ellipsoidal (the 2D projection of a 3D ellipsoid is an ellipse), while the spirals are disk like and hence much flatter (but they do have a halo). The spirals have an angular momentum and rotate about an axis, while the ellipticals are supported (i.e. their shape stays more or less stable) due to the seemingly random motion of stars in them. Broadly speaking ellipticals contain relatively older stars (red) while the spirals tend to have younger (blue) stars. Several different intermediate types are shown in Fig. 3. GalaxyZoo is a site that allows you to help in classifying galaxies (http://www.galaxyzoo.org).

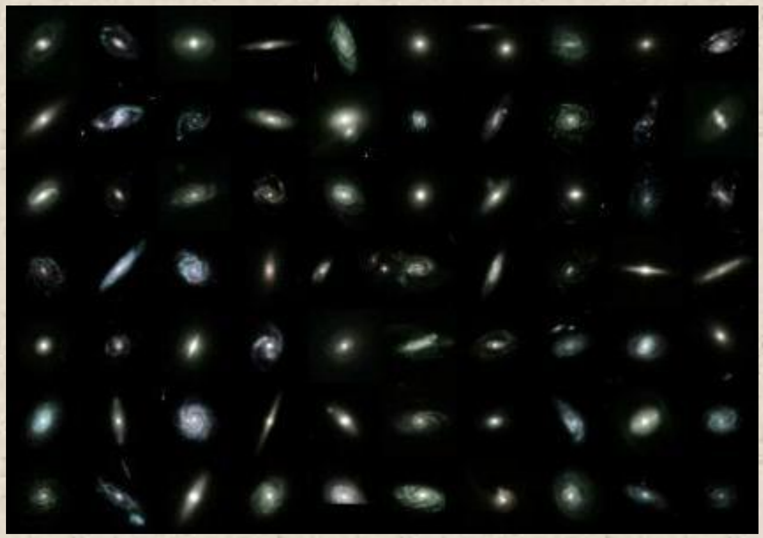

Fig. 3: A variety of galaxies from the GEMS survey
Credit: http://www.sciencedaily.com/releases/2004/01/040120034341.htm

Spectra show that distant galaxies are receding from us (i.e. from our Galaxy) with a greater velocity (this 'redshift' is the same as the Doppler shift you experience when a train is receding from you on the platform – the apparent frequency of the sound changes). This leads to the conclusion of an expanding universe. But the universe is not expanding "into" something. The entire universe itself is expanding. The galaxies themselves are not getting bigger and bigger. In the analogy of a balloon being blown into, galaxies are not inkblots drawn on the surface of the balloon (these would expand as the balloon is inflated) but rather like small coins stuck on the surface of the balloon (which would not expand). Now the redshift (i.e. the factor by which a wavelength shifts redward when a galaxy is moving away compared to if it were stationary) is synonymous with distance.

Initially however determining the distance was problematic especially because the galaxies show no parallax due to their large distances from us. This is exactly how the moon seems to travel with us when we are riding on a train (i.e. no parallax) but objects nearer the train seem to move faster compared to farther objects. What helped immensely was the discovery of "standard candles" i.e. objects which have well understood luminosity. A type of stars known as Cepheid variables is an example. These giant pulsating stars change in brightness during different periods of Hydrogen and Helium burning. The intrinsic brightness (called absolute magnitude) is directly related to the period of variation and can be determined by measuring the period. Apparent magnitude is the measured brightness (from Earth). The difference between the two tells us the distance to the star. Once these stars were identified in nearby galaxies, it was a simple matter to determine the distance to these galaxies.

For galaxies that are further away we can no more see individual stars or their variations. Unless the star dies in a magnificent explosion becoming a Supernovae. Supernovae of certain types of stars attain a fixed maximum brightness. By measuring the apparent magnitude of the SuperNova we can now get the distance to such a farther off galaxy. Such different standard candles together form what is called the distance ladder allowing us to measure the universe at different scales.

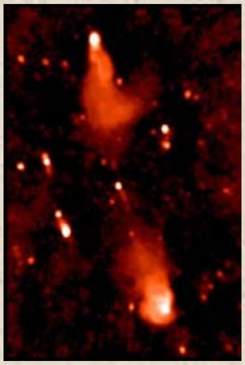

Fig. 4: Example of an FRII galaxy. In optical only the central star-like object would be seen. The two lobes are visible at radio wavelengths. Radio jets start from the center of the galaxy and go a great distance at very high-speed before they get slowed down by the surrounding material.
Credit: www.cv.nrao.edu/~abridle/aj00nvss/aj00nvss.html

The hundreds of billions of stars in a galaxy result in its being the luminous object that we perceive. But the whole is greater than the sum of parts. There are density waves as are apparent in the spiral arms of a galaxy, there are blackholes that inhabit almost all galaxies, there are dust lanes, warped disks and so on. A fraction of galaxies also emit copious amounts of radiation at radio wavelengths and/or in x-rays. Fig. 4 shows such an example. It is due to this property that many galaxies that are faint in optical but otherwise energetic can be found by surveying at, for example, radio wavelengths.

The farther a galaxy is, the longer it takes its light to reach us. So when we do see it, we are seeing it the way it was millions of years ago, or for the farthest ones, billions of years ago. We can thus learn of how galaxies evolved as well as the conditions in the early universe.

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* You will of course be surprised if you are in the Southern Hemisphere since there you can see the two Magellanic clouds which are satellites of the Galaxy. They loom large almost like clouds and are bound to catch a straying Northerner off guard.

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