XIII. Galaxies and the Structure of the Universe

1. Proof of other galaxies

As I had mentioned before, even by 1920 it was not clear that there were other galaxies besides the Milky Way. A large faction of astronomers wanted to find a place in the Milky Way for all other known objects in the sky, whereas another faction made arguments that objects, such as spiral and elliptical nebulae were far beyond the reaches of the Milky Way. In the 18th century, Charles Messier, a French astronomer had compiled a catalogue of nebulous objects in the sky, which presented a nuisance for his search of comets. This Messier catalogue is still in use. It contains a variety of objects, such as real gas nebulae like this planetary nebula or the Orion nebula along with known clusters of stars. From our studies of the life cycle of stars we know that the Orion nebula is a place in the Milky Way where new stars are born.

We know that planetary nebulae represent the ejecta of an aging star, which clearly is a member of our Milky Way.

We have also discussed the globular clusters, such as M13, which Harlow Shapley used to determine the location of the solar system in the Milky Way. They orbit our galaxy and are clearly bound to it by gravitation.

However, the catalogue also contains objects such as M100 that, as we know now, closely resemble our own Milky Way galaxy but all this was not yet known at that time. Finally, there are the most prominent nebulae in the southern sky, the Small and the Large Magellanic Cloud, which contain millions of stars and are now recognized as two small companion galaxies to the Milky Way.

This was the background for a famous scientific debate, the Shapley - Curtis debate. Harlow Shapley, the one who had put us into the right place in our own galaxy, argued for a universe completely contained within our Milky Way. He claimed the following:
- He had found, by using Cepheid variables as distance indicators, a diameter of the Milky Way of 300,000 LY, while the distance of the LMC from us is just 75,000 LY.
- He used as an additional important argument, i.e. that another astronomer, Van Maanen, had apparently found indication that the rotation of the Andromeda galaxy is recognizable through a visible displacement of stars on the other fringes within a relatively short observation period of several years. If Andromeda were as far away from the Milky Way, as Shapley’s opponent Heber Curtis claimed, the rotation of the outer fringes of Andromeda would have to be faster than the speed of light (impossible after Einstein’s theory of relativity).

The main arguments of Curtis for the nebulae to be "island universes" beyond the reaches of the Milky Way, as he put it, were the following:
- From the observation of Novae in Andromeda he found a distance of more than several 100,000 LY.
- He also pointed out that no spiral nebulae were seen in the plane of our galaxy, where he expected them most likely, if they were part of the Milky Way itself.
- Finally, Vesto Slipher had reported that galaxies showed a consistent red-shift, i.e. they were apparently moving away from us. He argued that this finding would speak strongly
against these objects being part of the Milky Way. Then they would have to be in a bound orbit about the center of the Milky Way instead of fleeing its reaches. (This observation will become very important in the last chapter.)

The debate ended without reconciliation. Both opponents maintained they were correct, and the audience remained split. The debate was finally decided by Edwin Hubble in 1924: He consequently used Cepheids to determine the distance of many nebulae. As a result, they turned out to be separate galaxies from our own with even much greater distances than Andromeda. He used the fact that he could observe the variation period and the relative magnitude. With the known luminosity of the Cepheids he derived their distance. However, the distance scale was still off by a factor of 3. The scale was calibrated in our galaxy with Population I stars, but Hubble mostly used Cepheids in globular clusters of the galaxies, which are Population II and thus fainter. All derived distances were 3 times too small. However, this takes nothing away from Hubble's great discovery and achievement!

Although Curtis’ arguments seemed somewhat weaker at the time of the debate, Curtis were ultimately correct. Why then did Shapley err so profoundly with his arguments? The trouble for Shapley was that

a) Van Maanen erred in his observations of the Andromeda rotation (it might have been wishful thinking. This is indeed a danger in any scientific discovery, and any scientist must be extremely careful.)

b) Shapley did not know yet that there are 2 types of Cepheid variables with a factor of $\approx10$ difference in luminosity, and this translated into a distance error of a factor of 3. Both Population I and Population II stars undergo the state of Cepheid variable, but at different luminosity.

2. Galaxy types

If we look through the collection of galaxies, we find that there is a beautiful variety of shapes. Again Hubble played a major role in defining an organization scheme. The most structured ones are the

a) Spiral galaxies.

Spiral galaxies are similar to our own Milky Way, which we can't see from outside, but we have derived the structure from within. This galaxy M65 looks very closely like what we think of our Milky Way. It has a large central bulge and a few relatively tight spiral arms. There are others with more open spiral arms, such as M100, which is observed looking almost exactly at a right angle to its galactic plane. Two spiral arms are clearly resolved here that wind around the center for more than 360°. This must create the illusion of more than 2 spiral arms when seen from within. Even more open is NGC 1566. Remember that the spiral arms are created by ongoing star formation from interstellar gas. The density wave of the spiral arm triggers star formation, according to the best fitting model. Therefore, new bright young stars light up the spiral arm and make them stand out.
As some of the galaxies are seen edge-on another important feature of spirals is obvious: they contain a lot of interstellar gas and dust, which block out the light in the center of the plane. The presence of gas and dust tells us that star formation is still very active in these galaxies as is in our own.

Galaxies with a straight bar in the center form another branch of the spiral galaxies, the barred spirals. The same ordering scheme as for regular spirals, now with SB (for barred spirals), applies for this parallel branch in Hubble’s scheme. The reason for the formation of such bars is still a complete riddle. Recent observations in the Milky Way have re-opened the discussion, whether we might live in a barred spiral galaxy.

b) Elliptical galaxies:

In contrast to the spirals there are relatively featureless galaxies, the elliptical galaxies. This is the giant galaxy M87, which appears almost spherical. Depending on their flatness, Hubble assigned them with E0 (for spherical) to E7 (for very flat). All these star systems have no gas or dust, and thus no young stars at all. They show almost no rotation and thus show no flat discs, but spheroids. In a sense globular clusters seem like very small elliptical galaxies. However, elliptical galaxies have very energetic centers like most other galaxies. As in the case of our own galaxy this is taken as an indication for super-massive black holes in their center. We will come back to this aspect later.

c) Irregular galaxies

Finally, there are very irregular objects, which are classified as irregular galaxies. They show no symmetry in their shape. The most likely reason for this irregularity is seen in the tidal force from its more dominant neighbor galaxy. This is evident for the LMC, which is very close to the Milky Way with its distance of only 140,000 LY.

d) Dwarf and faint galaxies

In addition, there are many dwarf galaxies between the major objects, which fall either into the elliptical or irregular category. What the relative contribution of these small objects to the entire universe is, can only be studied with the most powerful of today’s telescopes. They may contribute to the missing mass on the scale of the universe.

More recently it is also debated whether the larger galaxies were formed out of many dwarf galaxies in the early universe. Observations with Hubble space telescope suggest that there were many more of these small objects in the early universe.

e) Why ellipticals and spirals?

This is still under debate, but some clear lines seem to form. At first it was thought that it shows the age of the galaxy: Elliptical galaxies have no young stars. However, this cannot be true, since there are old stars in both types of galaxies. The reasoning concentrates on the major difference between elliptical galaxies and spirals: elliptical
galaxies have no gas and dust and thus no young stars. This cannot be caused by the difference in rotation, which is also observed. The lack of rotation of elliptical galaxies must rather have the same reason as the lack of gas and dust.

However, some spectacular objects in the sky suggest that Galaxies collide, not even infrequently. As in this case. It looks more dramatic than it actually is. The collision of 2 galaxies mainly means a penetration with their major shape intact. In particular, this will not lead to many star collisions. The distances between stars are far too huge. Remember:

If the sun is of the size of this Styrofoam ball, the nearest star is in San Francisco (as we have seen earlier). Imagine the feeble chance that 2 stars meet even over the life of the entire universe. This will not be changed significantly when 2 galaxies meet.

But why do galaxies collide, aren't their distances even more impressive? Yes and No, if we compare the distance of 2 galaxies with their size, we must hold 2 dinner plates at arms length. This is an incredible difference. While moving with respect to each other, the chance for 2 galaxies to meet is fairly high. As we will see galaxies are grouped in clusters, and within such clusters collisions are relatively common, like accidents in traffic congestion regions during rush hour.

What then does really happen during a galaxy collision? Gas and dust will be compressed, like during the impact of a supernova shock wave. This stimulates a rapid burst of star formation, which consumes a lot of gas. Therefore, later on no raw material is available any more for making young stars. The penetration of the gravitational fields cancels angular momentum of the individual galaxies, i.e. they rotate much slower afterwards. Finally, most of the hot gas is ejected and left behind. Ergo, such a scenario seems to explain naturally all features of elliptical galaxies. The most likely conclusion therefore is that elliptical galaxies are such that have already gone through at least one collision.

3. Galaxy Clusters

These collisions are most frequent in clusters of galaxies. Let us study galaxy clusters a little more. Lonely galaxies seem to be very rare in the universe.

a) Local group.

Our own Milky Way is a member of the Local Group. The most prominent members are the Milky Way and Andromeda. Both have companions, the LMC and SMC of the Milky Way and M32 and M33 of Andromeda. In addition, there are several small galaxies. This small group is part of the larger Virgo cluster.

b) Types of Clusters

We distinguish between 2 types of clusters
- Regular clusters with approximately spherical shape and solely elliptical galaxies.
- Irregular clusters: which are not so symmetric and contain both elliptical and spiral galaxies.
These 2 types of clusters provide additional evidence for a scenario with collisions as the reason for a transformation into elliptical galaxies. Collisions tend to equalize motion, thus a spherical cluster should result from collisions. Incidentally, spherical clusters also contain only elliptical galaxies. Since the collisions at slow relative velocities may not leave the galaxies intact, there is the chance of galaxy merging. As a result some clusters have giant elliptical galaxies at their center. This is known as "galactic cannibalism". These giants for sure have undergone collisions.

Finally, regular clusters are known strong X-ray emitters. Like this one as observed by ROSAT. The reason is a huge amount of very hot gas between the galaxies, which has been swept out of galaxies during collisions. The gas is so hot that it emits most intensely in X-rays. Very recently the measurement of the temperature of this gas in X-ray has provided an independent check of the total mass of such a cluster. The mass to keep the hot gas together is again 20 times as high as the mass of the individual galaxies.

4. Masses of galaxies

Since gravity is what keeps everything from flying apart, mass is the key parameter for all celestial objects. The following will be a brief repetition of what we know already: As for all other objects, we determine the mass of galaxies from the motion within them or the motion about each other. The tool is Kepler's 3rd Law.

a) Spiral galaxies:

As within our galaxy we use galactic rotation curves to measure the velocities of the stars orbiting the center. A general finding:
- There is rapid rotation in the center, which indicates a huge mass concentration that could be responsible for the activity observed in such centers.
- The velocity remains high in the outskirts, which indicates a huge halo of mass that is not visible. This constitutes missing mass on the scale of individual galaxies.

b) Elliptical galaxies:

In elliptical galaxies the broadening of lines from the overlapping of many star spectra is used to measure the velocities. Again there are high central velocities which may indicate super-massive black holes.

c) Binary galaxies:

As in the case of Binary stars, Binary galaxies present another way to get the galaxy mass. The velocities of the galaxies are measured using the Doppler effect. In this case we get with Kepler’s 3rd Law both masses separately. The motion of the LMC has provided us with another tool to check the mass of our own galaxy, which also tells us that it is $10^{12}$ solar masses.

d) Galactic clusters:

Finally, we see as in the case of the nearby Virgo cluster that most galaxies are found in more or less compact groupings. Using the Doppler effect again we get the velocities of all member galaxies. One step higher in the hierarchy of matter grouping we determine masses in the same way as in star clusters.
In all cases we deduce the amount of gravity needed to keep the stars or galaxies from flying apart. Also on this step of the hierarchy we find that much more mass (10 to 20 times as much) is needed than can be accounted for by the sum of the visible galaxies and stars. I.e. there is a
dark matter problem everywhere in the universe and on all scales.

5. The Galactic Distance Scale

Before we extend our view into the entire universe let us review our methods to measure the distances, since this is the important tool to scope out the entire universe. We will see that all methods build on each other starting from the short distances in the solar neighborhood. This is like a Distance Ladder. Consequently also the errors in the very first method will show up to the very end of the ladder. Therefore, the utmost accuracy is required, in particular, in the beginning in order not to end up with a totally unreliable distance scale.

A) Distance Ladder

We have leapfrogged our way into the universe by building distance measurements always on shorter distances that we have measured already with a method that reaches up to a certain limit. The distance to the closest stars can be determined, using the parallax method, i.e. the diameter of the Earth’s orbit is used for triangulation to the stars. This is the most direct method, which works with the most recent data from the European satellite Hipparcos up to a few 1000 light years. For more distant stars and galaxies we have to resort to methods, which only can be calibrated by using this first method for the closest stars. Therefore, we rely on the accuracy of every step that we have taken before. Basically we have used two groups of methods:

1. In one branch we use Standard Candles
   - i.e., we "know" luminosity + measure apparent brightness -> Distance.

   We have used this type of method in the form of spectroscopic parallax and with the Cepheids. For the largest distances we can add the luminosity of supernovae Type Ia to this tool set, as I mentioned when talking about them. Type Ia Supernovae are excellent Standard Candles, since all of them have the same luminosity. They go off exactly, when the white dwarf reaches a mass of 1.4 times the mass of the sun. The enormous luminosity of the supernovae (they outshine an entire galaxy) leads us finally to the edge of the universe with our distance determination.

2. As a second branch we also use Standard Rulers
   - i.e., we "know" the size + measure angular size in the sky -> Distance

   The parallax method is the ancestor of this family of methods (in a way we use the known diameter of the Earth’s orbit). It is the key representative for all other methods that use a known size of an object. For larger distances we add the knowledge of the typical size of globular clusters and of large galaxies to our tool set.
The values obtained with such “Standard Rulers” are not so precise any more, since they are known only on the average and there are variations among different objects. However, this alternate method of distance determination (in addition to standard candles) helps greatly to double-check the distance scale and to boost our confidence in the values. The use of Hubble Space Telescope has allowed us to find many Cepheids in galaxies at much greater distances than before. Together with the work on parallax with *Hipparchos* this has led to a much more precise distance scale.

**B) Hubble’s Law (1929):**

A further revolution was introduced into the picture of the universe, when *Edwin Hubble* found in 1929 that the universe is not stationary and the distant galaxies move away from us, the farther away the faster. He found this by means of measurements of the Doppler effect at many galaxies, known spectral lines, e.g. those of H in these galaxies are redshifted.

In fact, *Einstein* had seen earlier in his General Relativity equations that a universe with gravitation could never be stable. It either had to contract or expand. Since he did not believe in such a universe at that time, he introduced an additional constant in his equations. (He called this the *cosmological constant.*) It was supposed to compensate for gravitation on the large scale. When he heard of Hubble’s discovery, he called this decision "the biggest blunder in his scientific career".

The result of Hubble’s observations is a simple relation.

\[ v_{\text{away}} = H \times \text{distance} \]
The recession velocity of the galaxies is a constant (known as the **Hubble constant**) times their distance. Since the distance measurements were improved dramatically the value of the constant changed over the last 60 years, but the relation remained the same.

As a consequence we see that the entire universe expands, as if something exploded and as if we were in the center of this explosion.

This view may give the impression, as if we were in the center of the universe, and all galaxies are receding from us. This is like being in the center of an exploding firecracker. But we have already learnt to be suspicious when we seem to be placed in the center. That was wrong several times. In Germany we bake a special cake, called Stollen, for Christmas, which has lots of raisins and yeast in it. When this Stollen rises the raisins move away from each other because the dough is forced to expand by the yeast. Raisins twice as far apart from each other move apart at twice the speed, just like in Hubble's law. So you can be on any raisin in the interior and you will see the same picture: the farther away a raisin the faster it rushes away from you.

Now we can use the measurement of the **red shift** of cosmic objects for
- the determination of the **spatial structure of the universe**
- a **trip back in time** (since distant objects have sent their light long ago)

The deepest and thus farthest look back in time has been performed by the Hubble space telescope in 1996. This piece of the sky extends just over a grain of sand held at arm's length.

Let us start with the first application of Hubble's law. For each direction in space we can prepare a "distance map", using the red shift of galaxies. A few years ago two Harvard astronomers Margret Geller and John Huchra have performed this job.

C) **Superclusters:**

The result of this survey is a universe which shows the galaxies grouped in clusters and super clusters, such as the "**Great Wall**", along **sheets** which seem to form thin walls around voids (like soap **bubbles**). These are the largest structures in the universe. Their formation, probably in the early universe is still - a **riddle**. Dark matter, which does not interact with our ordinary matter, seems to be necessary for the explanation, but nobody can tell yet what this matter might be.
6. Active Galaxies

As the red shift of the spectra of galaxies can be used to determine their spatial distribution it also provides the means for a trip back in time. Since light travels at a finite speed each distance can be converted into a time. Therefore, light can be viewed as a time machine. The farther we look in distance the farther back in time towards the early stages of the universe we go. As we will see there seem to be some distinct differences in the appearance of galaxies when we go far enough. But there are also enough similarities, which give a hint of what might be happening. In order to provide a baseline for the comparison let us first collect some features of galaxies, which are closer to us.

A) Centers of Galaxies

The center of our own Milky Way galaxy is more violent than any other location within.

Only radio, IR and gamma radiation allows a closer look because of the blocking dust. The total radiation from the region is of the order of 10 million suns, and a mass of about 3 million suns must be concentrated within a diameter of less than 2 light months to keep up with the high orbital velocities of objects in the central region. Massive molecular clouds are seen rushing away from the center, as if a giant explosion occurred in the not too distant past. Pictures from Hubble space telescope have shown that also other galaxies have high star and mass concentrations in their center like in the case of this elliptical galaxy.

B) Radio Galaxies.

However, the events in our own galaxy or other normal spiral and elliptical galaxies are dwarfed by much more energetic monsters which were revealed with the advent of radio astronomy. The giant radio source Centaurus A with an output of $\approx 10^{37}$ W almost outshine the entire Milky Way with just its radio emission. With radio interferometers, using our home planet Earth as the baseline, very detailed maps of such objects have been drawn, which often reveal a double lobe structure with a very energetic center in between. Energetic jets seem to emerge from a center where an unusual galaxy could be identified. It looks like an elliptical, but shows a strong band of dust. It looks as if a giant explosion has happened in the past. The jets emerge perpendicular to the galaxy's plane.

Some galaxies also show the jets in the visible light like M87, which is the giant center elliptical galaxy of the nearby Virgo cluster. A photo taken by Hubble reveals the center of the galaxy and a line of blobs, which point away from the galaxy. The connection with the galaxy is demonstrated in this picture which shows the entire galaxy, the center and the jet. In order to cope with the large dynamic range (from very bright in the center to the faint outskirts) an image enhancing technique on a computer has been used.

In many cases just one jet is seen as in the case of M87
whereas other radio galaxies clearly show two jets emerging to the opposite sides. Why this difference? The reason is that the radiation emitted into the forward direction appears brightened. It seems "compressed" since the light source is following almost at the speed of light. For the receding source, the beam into the opposite direction, the result is a dimming. For radio galaxies that feature 2 jets they must emerge almost perpendicular to the line of sight. Only then we see their light (or radio emission) with approximately the same intensity. The radio jets reach out into space up to 20 million light years (for the largest known objects), which amounts to 10 times the distance between Andromeda and us. For such huge objects the shape of the jets must be influenced by the surrounding medium. Slide XIII.33

If, for example, the parent galaxy of the jets moves through the intergalactic gas of a galaxy cluster, the shape of the jets give a vivid impression of the galaxy's motion through the cluster.

Another picture taken by the Hubble telescope of a different active galaxy shows molecular clouds which rush away from the center like in our own galaxy. The information on the motion has been obtained by making use of the Doppler effect.

C) Seyfert Galaxies.

How can we be so sure that the jets emerge from the galaxies perpendicular to their plane of rotation? In elliptical galaxies this plane is not obvious. There are also spiral galaxies with very energetic "star-like" centers. Slide XIII.35

A galaxy like this one is called a Seyfert galaxy. Its center is like the center of the Milky Way, but much more energetic. The center appears very bright and blue. 10% of these galaxies are strong radio emitters. And in these cases it is obvious that the jets emerge perpendicular to the galaxy disc.

D) Quasars

In 1960 the first spectra of bluish star-like objects were obtained which were known as very strong radio sources, but had not been identified previously. Not knowing what they were, the objects were called Quasars, standing for "quasi-stellar radio sources". Slide XIII.36

They look star-like, but emit radio (synchrotron), IR, UV, X, and γ rays. Some of these objects are even radio-quiet, i.e. they emit very little in the radio regime. However, they are still called quasars, which seems a misnomer. 3 years later strong emission lines in one of these objects (3C273) were identified as hydrogen lines, which are red-shifted that much that a speed of 16% c was derived. Slide XIII.37

Other quasars were found with enormous red shifts: 3C48 with about 30% c and another one with record breaking 94.5% of c. According to Hubble's law these objects must be far away and thus also be objects of the early universe. Most recently, a quasar has been found with the Chandra X-ray satellite that is almost 13 billion light years away. As a consequence they must have a huge luminosity to be visible so well. For some astronomers this interpretation posed a problem, and they looked for alternatives: The red shift could also signal that these quasars are objects of our own galaxy, but rushing away with an enormous velocity. Then quasars could be close to us, and their luminosity would...
be only modest and not such a spectacle. However, then we would expect to see similar objects, for example from Andromeda, that should also show a blue shift, since at least some of them must be ejected from Andromeda towards us!

One observation, for which the distance seemed to cause another big problem at first, was the finding that some quasars, such as 3C273, seem to eject jets at velocities greater than the speed of light. Were they closer to us, the observed speed would be less than c. However, this puzzle can be solved in a different, very natural way: View XIII.6, a View XIII.6, a

The jet is ejected almost into the direction of Earth (almost, but not exactly) with almost the speed of light. The jet almost competes with the light from the point where the jet started in a race towards us. In the short time difference between the arrival of light that was emitted from the origin of the jet and of light that was emitted somewhat later, when the jet has already moved quite a distance towards us, the position of the jet in the sky appears different quite a bit. In fact, the distance appears larger than could have possibly been traveled at the speed of light. However, the measured speed does not represent an actual motion. The fact that the light that we observe from both objects left them at a different time played a trick on us. These features provide us with one commonality between quasars and ordinary or active galaxies: the ejection of jets.

E) BL Lac Objects.

As a confirmation for the cosmic distance of quasars comes the observation that some quasars are found in galactic clusters with the same red shift, i.e. at the same distance, as the quasars. In addition, a class of objects has been found which clearly connect quasars with galaxies: BL Lacertae objects. These galaxies are very faint (since very distant) elliptical galaxies with very energetic quasar-like centers. That we only see very few such objects is probably due to the fact that generally the intense quasar hopelessly outshines its galaxy (or what may become a galaxy in the future), in the same way as the sun outshines its faint corona. As we use an eclipse to study the corona, we can only make the galaxy portion of the BL Lac objects visible by covering their bright center in the telescope. This is another objective for Hubble space telescope, which was designed to separate faint objects from neighboring bright sources! After the first repair mission also this goal has been achieved and many more such objects were found.
The **distance of quasars**, i.e. their **location in the past of the universe** and their connection with galaxies seem to indicate that quasars are an important piece of the puzzle of the **evolution of galaxies** and the entire universe. Quasars may be the nuclei of **forming galaxies**?

F) **Energy Source of AGNs and Quasars**

As already mentioned, the enormous distance requires a huge luminosity. The total energy emission can be as high as $10^{40}$ W (i.e. $2.4 \times 10^{13}$ times the luminosity of the sun), i.e. more than 100 times the output of the entire Milky Way galaxy. What makes this even more amazing is the fact that this energy emission can vary significantly within days. Since the **light emission** can only **change** in concert **over a distance which can be reached at the speed of light**, this must mean that the size of the emitting region is only a few light days, or 1000 astronomical units in diameter (just somewhat larger than our solar system). Therefore, this enormous energy must be generated in extremely small and compact regions. There is no way to get a large object to change that quickly. Even if it did, we’d see photons arrive at different times, and this would make the variation slower. The energy flux from 100’s of galaxies is generated in something like the size of the solar system.

Regular galaxies, radio galaxies, Seyfert galaxies, BL Lacs as cores of **formed galaxies**, all have bright, point-like centers with an enormous energy output. If we compute with **Einstein’s formula** $E = mc^2$ how much **mass** has to be completely **converted into energy**, we come up with a huge amount. This ranges from **1/20 of the mass of the Earth** for the center of the Milky Way to the mass of **2 suns every year** in the most energetic quasars. In reality it must be even more mass, since no energy conversion can ever work at 100% efficiency. **Nuclear fusion** is much too inefficient to provide the amount of energy in such a small volume. Then the hydrogen of at least 300 million suns would be burned up in only 1 million years. All this seems to be **evidence** for the accretion of huge amounts mass into **super-massive black holes**. Only this cannibalism works at an efficiency of roughly 50%. From the dynamics of material close to galaxy centers (i.e. the fast motion of stars in the centers) it is deduced that several million to several 100 million solar masses are compiled within at compact region. This could only fit within the confines of a black hole. Therefore, this seems consistent.

Depending on how much mass is available for the black hole to be swallowed at one time or another the luminosity may change. In regular galaxies the black hole may have cleaned its surroundings. In any case it will have **a giant accretion disc** around it because of the **angular momentum** of the material. This scenario would also explain the jets perpendicular to the plane of rotation: This is the only way out. The infalling material from the accretion disc forms an impenetrable barrier, as can be shown in computer simulations. If material makes it out, it is forced out at the poles. The accretion disc itself provides the pressure for the material to be squeezed out. The jet may simply be a hydrodynamic feature due to the enormous pressures built up by the accreting material or it could be particles accelerated along the magnetic field lines that emerge at the poles of the structure like in the case of a pulsar.
This question is still not solved yet. Hubble space telescope has provided us with some evidence that seems to indicate a void structure in galaxy centers, which might indicate the black hole.