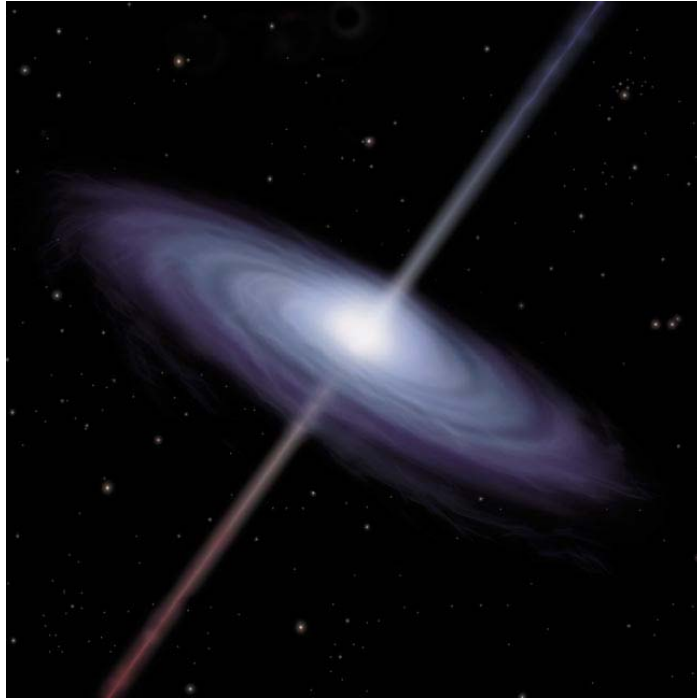


Supermassive Black Holes



by Samuel Joseph George

The concept of supermassive black holes has been around since the early 1960s. This idea arose from observations of Quasars (quasi-stellar radio source), then known as “radio stars” because of their strong emission of electromagnetic radiation in the radio part of the spectrum and what is seen as an almost point source in the optical spectrum. Quasars are now known to be galaxies that have an active nucleus. [2]

This concept is a relatively new one, especially in comparison to the idea of black holes; it was the great French mathematician and philosopher Pierre Simon Laplace that first suggested a model of a system which is now similar to that of a black hole. Laplace in the eighteenth century calculated that light behaved like particles rather than waves, as these behaved like ordinary matter under gravitational fields, then if a body had a sufficient mass then the escape velocity could be in fact larger than the speed of these particles. This is very similar to current theories of black holes, where nothing not even electromagnetic radiation can escape. As Laplace had suggested this electromagnetic radiation has particle behaviour in the form of photons.[2]

The modern concept of a black hole originated in 1939. Originally J. Robert Oppenheimer and Hartland Snyder argued that once a massive star has exhausted all of its nuclear fuel it will suffer a catastrophic collapse and will not become a white dwarf or a neutron star, these are stable states of matter, but will continually collapse. This will mean at a point near the end of collapse there will be a point when the effects of general relativity will dominate. Black holes are regions of space-time which have been curved to a point that effectively cuts them off from rest of the Universe. A black hole will have a specific limiting radius, which is called the Schwarzschild radius; this point is often referred to as the event horizon. [1] Past this point photons can escape the pull of the black hole; the non-relativistic Schwarzschild radius, R_{sch} , of a black hole is given by:

$$R_{sch} = \frac{2GM}{c^2} \quad (1)$$

Black holes are a solution to Einstein’s field equations and are now seen to not only exist as a mathematical consequence but, by indirect observation, to exist. [1]

In theory the concept of supermassive black holes being the “powerhouse” of active galactic nuclei is quite persuasive; however the problem is that it is hard to be able to achieve imaging data of these objects. A large black hole with a Schwarzschild radius of 10^8 of the mass of the Sun would still only produce a black hole with a radius of 2 AU. At these distances AGNs will be impossible for even the Hubble Space Telescope (HST) to take images of them, to get around this problem indirect methods of observation must be used.

Black holes can be “seen”, not by them radiating like stars do, but by the radiation from the accretion disk which surrounds them. The motion which the gas in the accretion disk needs to orbit a black hole is immense and so leads to high thermal temperatures, of the order of 10^6 K, at this temperature the radiation that is emitted is well within the X-ray part of the spectrum. There is a limit to the amount of radiation which is produced when matter falls into the accretion disk; this is known as the Eddington limit. This is produced by the outward force of radiation which is scattered off electrons which are free in the accreting gas. [1] Sir Arthur Eddington calculated this limit by noting that the increased radiation pressure opposes the gravitational

increase of matter, this will eventually lead to an equilibrium position. [1] The assumption that the matter falling into the accreting gas is fully ionized hydrogen is also made. So by equating the gravitational force and the force from the pressure the Eddington limit can be found [1]:

$$\frac{GmM}{R^2} = \frac{\sigma L}{4\pi cR^2} \quad (2)$$

From this the luminosity, L, can be found (where σ is the Thomson cross section $\sigma = 6.6 \times 10^{-25} \text{ cm}^2$):

$$L_{Edd} \approx 1.3 \times 10^{38} \left(\frac{M}{M_{\odot}} \right) \text{ ergs}^{-1} \quad (3)$$

This has the implication that if a body is emitting radiation greater than the Eddington limit then it would break up from its own photon pressure. Fortunately Quasars have been observed to radiate at approximately their Eddington limits, this supports the notion that the radiation seen in Quasars is actually due to an accretion disk which is surrounding a large black hole. [5] One of the first examples of these was seen by the HST in December of 1995, Figure 1 shows NGC 4261, this is thought to be a black hole accretion disk at the centre of a Quasar.

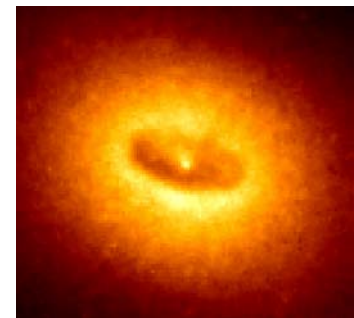


Figure 1

The Eddington limit provides a starting point for evidence that at the centre of a Quasar may black hole which is considerably less dense than what is seen to be a “normal” black hole. This is due to the fact that the density of a black hole will decrease as their size increases; it is an inverse relationship, so as the radius (or mass) increases then the density will decrease. [1]

Along with the Eddington limit there is other evidence that would suggest that black holes are present in the centre of Quasars. In the 1950s a Russian Astronomer Iosif Shklovsky showed that the radiation that was being observed from the Crab Nebula was a form of radiation called synchrotron radiation, after this discovery it soon became realised that the strong radio sources in the Universe were due to the object emitting synchrotron radiation. [2] [3] The emission of synchrotron radiation is a strong indication that there is a black hole in the centre of Quasars; this is because synchrotron radiation is present in accretion disks orbiting black holes. Synchrotron radiation is produced when an electron spirals through a magnetic field and as the electron is accelerated it emits a photon. This concept is very useful to make observations as it is distinguishable from the blackbody radiation. [1] [2] [3]

The synchrotron radiation will be produced in a jet which is perpendicular to the accretion disk. An example of these jets being produced is seen in Figure 2, this is NGC 4261, this time from a ground based observation. In this case instead of seeing the central part of the Quasar the jets of synchrotron radiation can be seen, this is further evidence at least for in the case of NGC 4261 that there is a black hole at the centre. Blackbody radiation is the simplest predicted continuous radiation spectrum which would be produced from a very thin accretion disk. In general however, apart from the fact that these jets are produced, the spectral shape predictions of this model do not concur very well with observations. [4]

If there is a massive central object in a Quasar then near this object there would be rapid rotation and high velocity dispersions. So this means that if there is a black hole then optical observations of the Quasar must indicate rapid rotation occurring at the centre of the Quasar and since the stellar density would increase near the centre then there would also be an increase in the amount of light that is produced from the centre of the Quasar. This theory was proved to be correct by observations taken by the HST. In fact not only was it seen to be the case that at the centre of Quasars but it also seemed to indicate that these black holes were common in the cores of every galaxy.

At the moment Quasars are rare, there are estimated to be one for every 100,000 galaxies. This however has not always been in the case. If one was to look at the Universe at about 10 to 20 percent of its current age Quasars would be much more common, this has been dubbed the “quasar era”. This can be seen by looking at Quasars with high redshifts, as you look at objects with high redshifts you are effectively looking back in time. As observations of Quasars at high redshifts are taken then it is seen that Quasar activity increases with a peak at approximately 3 billion years after the big bang. At this point the Universe was much smaller than it is at the moment; this means the galaxies would be closer together (approximately 3 times

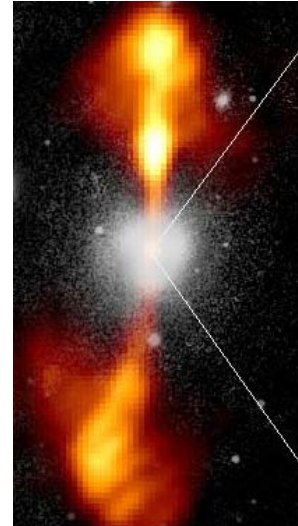


Figure 2

closer on average than they are now). This seems not to be quite logically, smaller size so if the amount of galaxies does not decrease then they would have to be closer together. The strange thing is that Quasars seem to be 30 times closer together! Since this is the case then perhaps it is a natural process that all galaxies go through just some had already completed it at this point. This would mean that higher redshifts then there would have to be more Quasars seen, however this was not the case, there seems to be a definite peak of the amount of Quasars in the Universe at this point. The obvious excuse to this problem is that there would be less Quasars seen with higher redshifts as they would be fainter. Even if this is taken into account then there still is less Quasars in the Universe. So maybe the idea of the “quasar era” is actually a quite important part of the evolution of the Universe. [3]

It would be logically to presume that Quasar activity would only start once the basis of galactic structure is formed and so there would be sufficient matter to able to feed a black hole. As the fuel runs out in the galaxy then the Quasars activity would stop, possibly to restart on the merger of two galaxies. [3] Perhaps this could happen in our own galaxy, it has been seen that there maybe a black hole in a state of hibernation at the centre of the galaxy. With the Andromeda galaxy moving towards us maybe in the distant future the two galaxies will merge to produce a Quasar.

The problem is that the question of the fuel which supplies the black hole running out does not explain the entire situation, perhaps the black holes predate the galaxies entirely and the galaxy forms around them, this would mean that black holes would be seeds to galactic formation. It seems that these questions can not be answered they require a greater understanding of galactic formation than is currently known. Observations of the spiral galaxy M33 have indicated that it does not contain a black hole and so has not gone through the Quasar state, if more evidence like this can be found then it would seem to indicate that the black holes would seem to form

concurrently with galaxies, assuming that there is not more than one type of galactic evolution - one that forms around a black hole and others that form by an entirely different process. [6] This idea would seem to be concurrent with the rate of Quasars seen increasing closer to the big bang. Quasars even during the highest peak were still 100 times rarer than “normal” galaxies. [3] Since Quasars are now less common in the Universe then it must be the case that some of these Quasars are now “hibernating”, starved of fuel waiting for accretion to start afresh. This would seem to be the only logical explanation to why there are so few Quasars seen.

Supermassive black holes are possibly the most destructive object in the Universe, the black hole once thought to be worthy of this crown has now seen to be outbided in terms of destruction. There are still many questions which need to be answered in the areas of research of supermassive black holes, a collection of detailed ideas has been put forward but until more is known about galactic structure then we will be effectively stuck in a hole, unable to understand these monstrous objects.

References:

- [1] Debra Meloy Elmegreen, “Galaxies & Galactic Structure” (New Jersey, USA; Prentice Hall, 1998)
- [2] Harry L Shipman, “Black Holes, Quasars, and the Universe”, 2nd Edition (Boston, USA; Houghton Mifflin Company, 1980)
- [3] Mitchell Begelman and Martin Rees, “Gravity’s fatal attraction: black holes in the Universe” (New York, USA, Scientific American Library, 1996)
- [4] Ian Robson, “Active Galactic Nuclei”, (United Kingdom, John Wiley & Sons, 1996)
- [5] Ajit K. Kembhavi and Jayant V. Narlikar, “Quasars and Active Galactic Nuclei: An introduction” (Cambridge, United Kingdom; Cambridge University Press, 1999)
- [6] Eugenie Samuel, New Scientist vol. 171 issue 2301, 28th July 2001, page 18.

Figure 1 & 2: Imaged by L. Ferrarese, John Hopkins University; and NASA, December 1995.

Front Page image:

Artist’s concept of a supermassive black hole highlights the accretion disk of gas and stars swirling around the black hole and the jets of material ejected along the poles, from constellation.gsfc.nasa.gov/education/images/BlackHole.jpg