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DOI: [10.1888/0333750888/2368](https://doi.org/10.1888/0333750888/2368)

# **Bright Quasar 3C 273**

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From

**Encyclopedia of Astronomy & Astrophysics**

**P. Murdin**

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ISBN: 0333750888

**IOP**

**Institute of Physics Publishing  
Bristol and Philadelphia**

**Downloaded on Thu Mar 02 22:49:19 GMT 2006 [131.215.103.76]**

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## Bright Quasar 3C 273

QUASARS are the most luminous objects we know in the universe. 3C 273 is among the brightest quasars; it also happens to be one of the closest to the Earth. It is therefore bright in the night sky and hence has been the object of intense studies since its discovery in 1963.

Quasars are found in the center of some galaxies (collections of some hundred billion stars; the MILKY WAY is the galaxy in which our solar system is embedded). Quasars are very peculiar celestial objects, they outshine the galaxy that hosts them, although they are barely as large as our solar system (which is extremely small compared with the galaxy). They emit electromagnetic radiation that covers all the bands accessible to astronomical observations on the Earth and in orbit, from radio waves to gamma rays. Their energy radiation can vary in an important manner on time scales that may be as short as hundreds of seconds. The matter close to the most central region of quasars moves at speeds of several thousand kilometers per second. These properties are most likely due to the presence in the center of quasars of a black hole that may be as massive as many tens of millions of suns. This paradigm is the only one that gives some hope of understanding the general properties of these objects.

### The discovery

Quasars were discovered in 1963 when it became possible to localize with precision RADIO SOURCES in the sky. 3C 273 played a major role in the discovery of quasars. 3C 273 is a bright radio source, it bears the number 273 in the third Cambridge catalog of radio sources (hence the name). It was the second source that was identified with a very peculiar 'star', a source of light that was not resolved as extended on photographic plates. The 'star', or better the source of optical light that was coincident with the radio source 3C 273, was soon seen to have peculiar emission lines. These are the signature of the presence of atoms that are excited and emit light at well defined wavelengths. Stars normally don't have emission lines, and more surprisingly it was at first impossible to recognize the type of atoms that were responsible for the emission lines in 3C 273, as the wavelengths at which the lines were observed were not among those emitted by known atoms. These very peculiar properties of the light source led to the name quasi stellar radio source that then became QSO for quasi stellar object or quasar for quasi star.

The mystery of the emission lines was solved when it was noted that one could indeed recognize the wavelength of the emission lines if one admitted that the lines are observed not at the wavelength  $\lambda_0$  typical of laboratory measurements of the atoms but at longer wavelengths  $\lambda = \lambda_0(1 + z)$ , where  $z$  is known as the redshift, equal to 0.158 for 3C 273. Many galaxies showing the same effect were already known in 1963, but with redshifts much less than that of 3C 273. In the universe this effect is a sign that

the objects are moving apart from one another (expansion) and thus are at very large distances. At a redshift of 0.158 3C 273 is thus found to be some 3 billion light years away. In 1963 3C 273 was the most distant object known (see also HIGH-REDSHIFT QUASARS).

Being so far away and still easy to find on photographic plates, 3C 273 is an object of 13th magnitude; 3C 273 is clearly a very luminous object indeed. Its light output corresponds to  $10^{14}$  times that of the Sun.

Most quasars do not radiate substantially in the radio part of the electromagnetic spectrum, and are called radio quiet quasars. A small fraction, of which 3C 273 is a member, do, however. These quasars are called radio bright quasars. They can be discovered as described above using radio data. Radio quiet objects are found by looking for redshifted emission lines in the light of 'stars'.

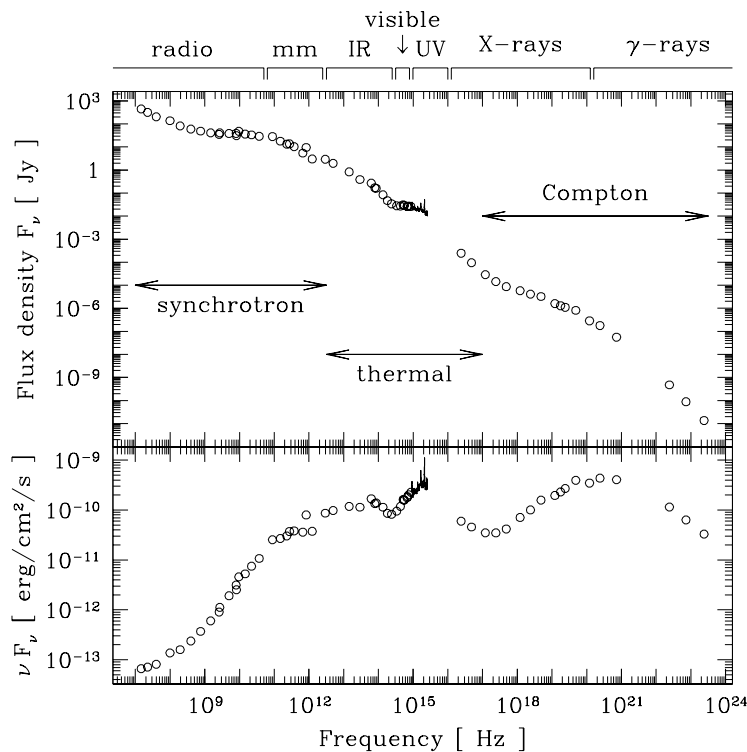
It was also soon discovered that 3C 273 varies in intensity on time scales much less than 1 year. Since light sources cannot vary on times scales much less than the time the light needs to cross the source (this is due to a causality argument: in order to significantly change the brightness of an object a signal must reach all the parts of the object to convey the instruction), it was also very quickly clear that 3C 273 must be much smaller than 1 light year, a distance already much less than that separating us from the closest star in our Galaxy.

The very unusual properties of 3C 273 spurred a large set of observations using not only optical and radio telescopes but also other instruments, both on the ground and on Earth orbiting satellites. It became clear that this (and other) quasar was the source not only of visual light and radio waves, but also of infrared radiation, ultraviolet light, x-rays and gamma rays.

Deep radio, optical and x-ray images in subsequent years showed that the object is not really 'star-like' but that a cigar shaped extension is associated with the main source (see figure 1 of QUASISTELLAR OBJECTS: OVERVIEW). This 'jet' extends from very small distances to some 20'' from the 'core'. It is most prominent in the radio images. Very surprisingly, the features making up the jet (often called blobs, thus expressing our lack of understanding of these features) were seen to travel away from the core of the object at speeds seemingly larger than the speed of light (superluminal motion). This superluminal motion is in fact due to an aberration that takes place when objects are moving in a direction close to the line of sight at velocities close to (but not larger than) the speed of light. This showed that in addition to the already very unusual observed properties of quasars one had to add the presence of radio wave emitting matter moving at very high speeds along a well defined direction, close to the line of sight.

### The source of energy

The only way known to us through which large quantities of energy can be released by matter in a very small volume, clearly necessary properties to understand the nature of quasars, is to consider that the matter falls into a very deep gravitational potential well created by a very massive and



**Figure 1.** The observed energy per unit area per unit time and per unit frequency (flux density) from quasar 3C 273 is given in the top panel. The emission mechanisms responsible for the emission are mentioned. The bottom panel expresses the same observations per log frequency interval. This shows that we observe roughly the same energy in all regions of the electromagnetic spectrum over 10 decades of frequency.

compact object. It is thus now accepted that quasars host very massive BLACK HOLES into which matter is falling at a high rate. One can estimate the mass of the black hole in the center of 3C 273 by remembering that light exerts a pressure on matter. The gravitational pull must be larger than this pressure for the matter to fall and its gravitational energy to be released. For 3C 273, the mass of the central black hole that is implied by this reasoning is about one billion solar masses.

The mass of the black hole provides a measure of its size; in the case of 3C 273 this size is of the order of  $10^{12}$  m. The corresponding light crossing time is 10 000 s or a few hours. This is well compatible with the fact that quasars (and in particular 3C 273) vary very rapidly.

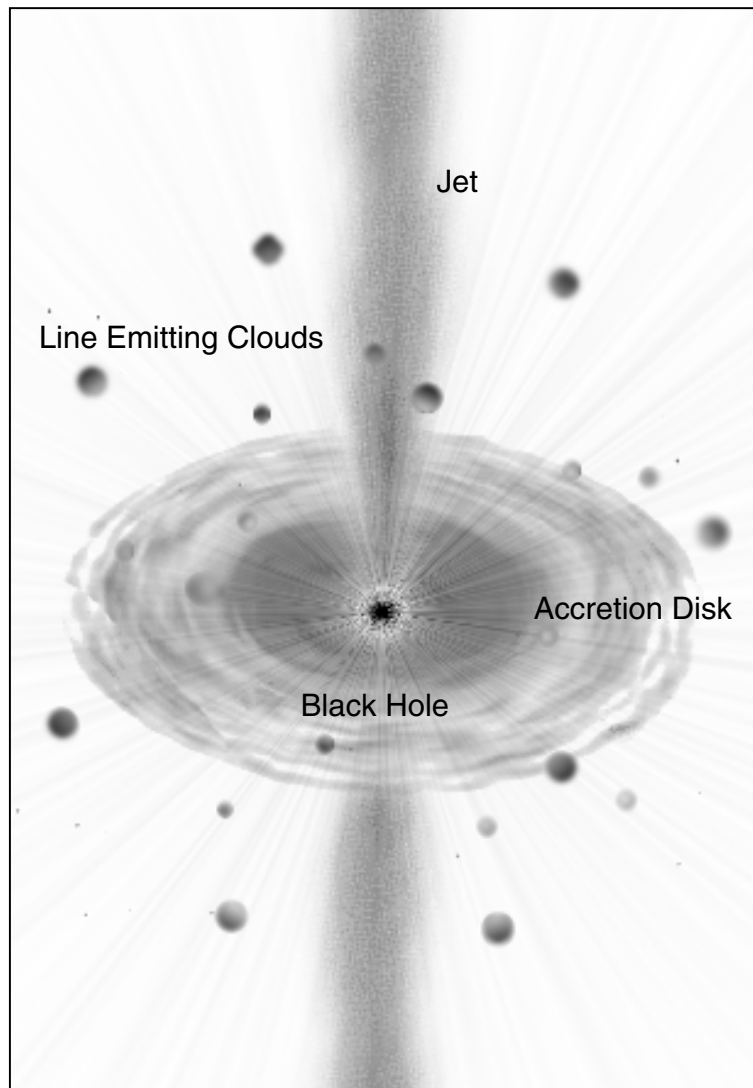
It is also possible to estimate how much matter must fall into the black hole to explain the observed luminosity by noting that the energy released by the fall is a fraction of the in-falling mass multiplied by the square of the velocity of light. This fraction is of the order of 10%. Again in the case of 3C 273, one finds that the rate of mass in-fall is about the mass of the Sun per year.

Going beyond these simple estimates to understand the true nature of quasars has proved a very difficult endeavor, that is still nowhere close to being finished. This is due to the very unusual properties of the objects compared with the better known celestial bodies and to the

very complex geometry of the sources. The latter property prevents one approximating quasars by spherical objects, the properties of which are identical when viewed from different directions. In quasars it appears that the observed properties strongly depend on the direction from which they are viewed.

### The radiation of quasars

The energy radiated by quasars is gained from the gravitational binding energy of the matter that falls into the black hole. This energy is radiated by electrons through several emission mechanisms. Electrons moving along bent paths radiate part of their energy as electromagnetic radiation. In quasars there are many ways through which the paths of electrons are bent; there are correspondingly many emission mechanisms. Magnetic fields are one way of bending electron paths. The radiation emitted by these electrons is called SYNCHROTRON RADIATION. With the parameters typical of quasars this energy appears as radio and millimetre waves. Hot electrons also move along complex paths in the thermal medium. These therefore also radiate what is called thermal radiation. In quasars thermal radiation is observed from heated dust in the infrared part of the electromagnetic spectrum and, most probably, by material heated in the process of the fall towards the black hole. This radiation appears in the



**Figure 2.** A popular view of the different elements making a quasar like 3C 273. The matter falls into the black hole on spiral paths in the accretion disk. The jet originates at the center of the disk. The line emitting clouds orbit the black hole.

visible and ultraviolet parts of the spectrum. A further way of bending the paths of electrons is through interaction with ambient light. These interactions are called Compton processes. Depending on the energy of the electrons the resulting emission appears in the x-ray or in the gamma ray parts of the spectrum.

We give in figure 1 the energy flux received at the Earth from the quasar 3C 273 and show which parts of this flux are caused by the mechanisms sketched above. We also give in the same figure the flux per logarithmic frequency interval ( $\nu F_\nu$ ). This representation gives the quantity of energy we receive in each region of the electromagnetic spectrum, i.e. as radio, millimeter, infrared, visible, ultraviolet, x-ray or gamma rays. It is striking to note that we observe roughly the same quantity of energy in all these regions of the spectrum. This is

described here for 3C 273; it is true in the same way for other radio bright quasars and with the exception of the radio emission for the radio quiet quasars. This is undoubtedly due to the interactions that exist between the different building blocks of the quasar.

Understanding these interactions is a question of intense research. The approach that is being mostly used is based on repeated observations of the quasar in as many parts as possible of the electromagnetic spectrum. One then uses the variations observed in different parts of the spectrum to see which variations lead others in time. One thus expects to slowly understand what are the more fundamental phenomena and what are the components that are secondary. One also hopes to understand the relative organization of the regions emitting through the components described above. This will hopefully lead to

a description of the geometry of the quasar.

One possible geometry is based on the presence of an ACCRETION DISK around the black hole. In this disk the material is slowed down by viscous forces and thus slowly falls towards the black hole, releasing its gravitational energy. These disks are called accretion disks; they are known to exist around much less massive compact objects within our galaxy. Their presence is rather naturally expected also around the much more massive black holes in the center of external galaxies. The jet is then ejected perpendicular to the disk, at its center. The emission lines are emitted by small clouds that orbit the system. This geometry is illustrated in figure 2. It should be noted that this is a possible way of understanding the organization of matter in quasars and is not yet firmly established.

### The future

Quasar 3C 273 was the first in which the very peculiar nature of these objects was recognized. It has been the object of intense studies in the 30 years since its discovery. Many of the observations have led to new insights and to more surprises. 3C 273 is certainly the best observed quasar and thus the best known. All the phenomena that are associated with quasars are seen in 3C 273, whether this makes it the archetype of a quasar or an exceptional object remains to be seen. What is certain is that understanding the physics of 3C 273 is still a challenge.

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