What Powers Quasars?

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1 Introduction

The modern era of the ‘violent universe’ began with the study of quasars (‘Quasi Stellar Objects’ or QSOs) in the 1960s. As the name suggests these were objects that looked like stars but in fact they turned out to be very distant and *extremely* luminous (emitting perhaps 10x as much light as an average galaxy of perhaps 100,000,000,000 stars).

Quasars were discovered when astronomers were trying to associate astronomical radio sources with visible objects. Some of these sources turned out to be connected with objects inside our own galaxy (such as the remnants of supernova explosions, or else regions where stars were in the process of forming). Other, however, did not seem to be associated with the galactic disk (their distribution looked isotropic - no variation with direction) which meant that either they were rather dim and so close to us that the width of the galactic disk did not affect the distribution of those we could see or else they had to be very, very far away, well outside our own galaxy.

Indeed, some where quickly identified with other galaxies (some of which had peculiar shapes) and some seemed to be associated with blank sky which could mean that they were so far away that nothing was visible with the rather inefficient photographic plates available at the time. In the latter case they had to be very luminous indeed.

The issue was resolved when some of the sources turned out to be related to very distant quasars which were even more luminous in visible light that the associated radio object. Developments in image intensifier technology also meant that we began to see very distant galaxies where we had previously only seen blank sky. An example is the source known as Cygnus A (also known by its radio catalogue number 3C405), which is the second most powerful radio source in the sky, after Cassiopeia A, which is a relatively close supernova remnant. (Note that we ignore the extremely close Sun in this ranking.) It turns out that Cygnus A, though extremely bright in the radio spectrum, is about 730 million light years away.

Not all radio sources are associated with quasars, but there are reasons for thinking that in many cases there are indeed quasars in the centre of the associated galaxy but that the light is blocked by surrounding matter clouds.

How are such exceedingly energetic sources of light and radio waves powered?

It turns out that we can go quite a long way in saying what is *not* possible using relatively simple physical arguments. When you have eliminated all the things that are just not possible, you are left with a relatively small number of options which, however unlikely they seem at first, may well be true. This is a project requiring mathematical calculation rather than observational interpretation.

2 Where do we start?

Consider Cygnus A and 3C273:

- How far away is Cygnus A? (I have told you, but you need to get a reliable citation and different authors do disagree.)
- How luminous is Cygnus A?
- Can we work out how much energy is stored in its radio lobes? (Yes we can - or at least we can do a *minimum energy calculation.*)
- Compare this to a mass using $E = mc^2$ and express it number of the solar masses that would need to be entirely converted into energy.
- How quickly would Cygnus A run through its stored energy? (Divide stored energy by rate of emission).
- Given the size of Cygnus A and the fact that nothing moves faster than light, could the radio lobes have expanded from the central galaxy without radiating away all their energy.
- Think also about adiabatic expansion of a radio lobe and how much energy it would lose expanding from the size of a typical galaxy.
- So why can we still see radio emission? What is feeding energy into the lobes?

- Look at the radio source 3C273 and its optical equivalent. Look at the latest radio maps of Cygnus A.
- There is a strong presumption of something very energetic going on down in the middle of the galaxy.
- Can we power these sources by continuous supernova explosions? What rate of explosions would be required?
- If we assumed that we had efficient conversion of mass to energy, what rate of matter consumption would be needed (in terms of solar masses)?
- What type of mechanism is involved right down in the middle there? Are black holes involved? How do we get energy out of a black hole? How does matter get sucked into a black hole (what type of journey does it have)?
- We know that some quasars are rather small because the light and radio emission varies on a short time scale. What is the logic here?
- What does the limit on size mean about the temperature that has to be attained in order to emit that amount of electromagnetic energy (assuming black body radiation). (Maybe NOT black body radiation?)
- Is there anything similar in our own Milky Way?

Answering these questions with straightforward (but not at all trivial!) calculations leads us to some extraordinary conclusions. ”Eliminate the impossible and what is left must be true.”