Astrophysics

The origin of gas in quasars — reverse stellar evolution?

from Martin Gaskell

WHAT is going to happen to a star situated next to the central energy source of a quasar as it is blasted by an intense stream of ultraviolet, X-ray and γ-ray radiation? A recent study by W.G. Mathews[1] makes the bold prediction that stars in such an environment will reverse the direction of their evolution!

One of the defining features of quasars is the presence of rapidly moving ($v \gtrsim 10^4$ km s^{-1}) gas clouds with densities greater than 10^8 particles per cm^3 (much denser than normal gaseous nebulae seen around hot stars). Because they produce wide Doppler-broadened emission lines these clouds are called 'broad-line' clouds and the region from which they come is called the 'broad-line' region. From considerations of photoionization equilibrium we can work out the distance of these broad-line clouds from the central energy source (the mean ionization depends on the intensity of ionizing photons and the rate of recombinations which depends on the density). This distance is about a light year for an average quasar. In Seyfert galaxies (a kind of low-luminosity quasar) the broad-line region is expected to be an order of magnitude smaller (light-weeks to light-months) and emission-line variability observations have independently confirmed this size scale[2]. We are very confident, therefore, that the broad-line region is extremely close to the central energy source of the quasar.

The origin of the broad-line clouds is one of the major mysteries of quasars. The gas has a relatively high density, intermediate between normal gaseous nebulae and the density of the outer layers of stars[3], and a chemical composition not very dissimilar from stars such as our Sun[4], but these facts tell us very little. It is the motions of the clouds that are potentially the most important indicators of their origin. In the past all possible kinematic conditions have been given serious consideration — rotation in a disc, random orbits, infall and outflow — but it is the radiative acceleration theory that has been worked out in the greatest physical detail[5-8]. Although the issue is by no means completely settled there is mounting evidence that the broad-line clouds are indeed preferentially outflowing (rather than orbiting or infalling). For example it has been known for many years (from optical absorption lines) that ionized gas is outflowing from many high-luminosity quasars and even Seyfert galaxies[9]. Recently discovered systematic differences in broad-line profiles[10] imply that at least the highest-ionization broad-line clouds are outflowing. Perhaps the most direct evidence in favour of the radiative acceleration model is the correlation between line widths and physical conditions of broad-line clouds[11]. This is readily explicable in radiative acceleration models (since the same radiation which is accelerating the clouds is also photoionizing them) but is hard to understand in models where gravity dominates the dynamics.

Despite the growing evidence in favour of the radiative acceleration model and the unsatisfactory state of alternative gravity-dominated models[12] the problem of the actual origin of the clouds is perhaps more acute than ever. In the radiative acceleration theory a relatively steady volume source of cloud material is essential since it is only gas starting outside some critical radius which is accelerated outwards. Gas clouds created inside that radius (for example, from tidal disruption of stars near the black hole or from the accretion disc) will fall inwards (this is in fact highly desirable since one needs an influx of matter to power the quasar). The stars within a light year or so of the central energy source are the most natural source of the broad-line clouds but it has been realized for some time that normal stellar mass-loss processes (for example, stellar winds) fail by an order of magnitude or two to produce the necessary mass outflow rates if the broad-line clouds are all being expelled from the nucleus. This has led some workers to consider whether the intense radiation of quasars can itself enhance stellar mass loss. An attractive possibility is pushing the gas off the surfaces of the many lower main-sequence red dwarf stars in the galactic nuclei by the same quasar radiation pressure that will accelerate it to high velocities[13]. While this can work for red giant stars, the surface gravities of red dwarfs turn out to be prohibitively high for this sort of radiative ablation and red giants are expected to be much too rare to provide enough mass.

Mathews[1] offers a startling way out of these difficulties by proposing that red dwarf stars close to a quasar have their internal structures changed by the quasar radiation and effectively reverse their evolution by expanding. These 'inflated' stars would have lower surface gravities and could be ablated by radiation pressure. The key fact Mathews points out is that low-mass stars in the broad-line region actually have more radiant energy incident upon them than they produce by nuclear reactions or gravitational contraction. Mathews argues that if more than a few per cent of this energy can be mixed throughout the star a new configuration will be reached with an expanded star having a lower central temperature. Low-mass stars would then evolve in the opposite direction to their original contraction, towards the main sequence (hence the term 'reverse stellar evolution'). The hard X rays can deposit their energy relatively deeply in the stars and from there it can be mixed throughout the star either by convection or by large-scale meridional circulation currents (analogous to the situation in Jupiter where the incident solar radiation could do the same thing). Once the star has been inflated (or rather re-inflated) the radiative ablation process can remove matter efficiently from the surface of the star. After some 10^9 years or so the entire mass of the red dwarf star will have been removed. When the quasar has exhausted its supply of red dwarfs its activity will die down. This is in agreement with observations which show that quasars were far more active 10^{10} years ago when galaxies were young than they are now. Mathews even goes so far as to suggest that a possible deficiency of red dwarf stars in the inner one light year of our own galactic nucleus[14] could be a result of past quasar activity.

The inflation/ablation model has a number of attractive points: it gives the needed enhanced stellar mass-loss rates; the distance from the X-ray source within which stellar inflation is possible is consistent with the size of the broad-line region inferred from completely different arguments; and the gas is automatically produced at the right density and temperature. Inflated stars are also more liable to collide and produce the hot 10^8K intracloud medium. The question of whether the inflation mechanism does actually work will, however, require more detailed studies to settle it. It is certain that a star next to a quasar cannot have a normal cool 3,000K surface, but just how the harsh incident X-ray flux will affect its internal structure is a very difficult thermodynamic problem depending on poorly understood theory. If the inflation process fails and some other adequate mass-loss mechanism cannot be found then the physical model for the quasar that has emerged in recent years will need radical modification. □

Martin Gaskell is on the faculty of the Astronomy Department at the University of Texas at Austin, Austin, Texas 78712.

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