A NUCLEAR REGULA-TORI MODEL FOR QUASARS AND SEYFERTS +

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Although VLBI reveals structure in active galaxies on scales as small as a few parsecs, this is still likely to be several orders of magnitude larger than the scales on which jets are accelerated. We must therefore rely on theory, bolstered by indirect evidence, to deduce the behavior of plasma immediately surrounding the "central engine". One hypothesis which has received much attention recently postulates that jets emerge from thick tori of gas which surround massive black holes. The low optical and X-ray luminosities of radio galaxies imply that tori in these objects would have to be supported by ion pressure[1], while tori in quasars and Seyferts may be supported by radiation pressure. Rees et al.[2] have proposed that two parameters, α(the ratio of viscous stress to pressure) and $\dot{M}/\dot{M}_E$ (the ratio of the accretion rate to the value associated with the Eddington limit), are sufficient to determine the general characteristics of a torus, independent of the mass of the black hole. While existing observations of radio jets do not contradict the existence of such a homology, systematics involving the broad emission lines in quasars and Seyferts suggest that the homology may fail in these objects, at least insofar as conditions at $\lesssim 1$ parsec reflect conditions in the torus. I report here on how the onset of nuclear reactions in a radiation-supported torus may break the homology, and regulate the properties of the broad line regions in quasars and Seyferts.

The maximum temperature, pressure and density in tori around black holes less massive than a few times $10^8 M_\odot$ is determined by the onset of nuclear burning; around more massive holes, self-gravitation is the limiting factor[3]. The limiting density $\rho_{nuc} \sim 3\times10^{-5}$ gm cm^{-3} implies a maximum mass which can settle into the torus at any one time. If matter is fed into the torus at too high a rate, then nuclear reactions will drive strong convection, which will drain away the excess mass by enhancing the turbulent viscosity and perhaps by driving a wind as well. These "nuclear regula-tori" will resemble the supercritical accretion tori discussed by Paczynski and Wiita[4] and others. For an accretion rate much greater than the Eddington value, the torus will need to have a low efficiency[5], which implies that it inflates to a radius exceeding $\dot{M}/\dot{M}_E$ times the Schwarzschild radius. However, for $\dot{M}/\dot{M}_E \gtrsim 5000\ (M_{hole}/10^8 M_\odot)^{-\frac{1}{2}}$

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the photospheric temperature drops below the threshold for helium recombination, and the required degree of inflation cannot be maintained[6]. When this happens, the torus produces more energy than it can radiate away, and a supercritical wind must develop.

The velocity of this wind, and the density and radius at which it becomes optically thin, are reminiscent of the parameters deduced observationally for the broad line regions of quasars and Seyferts. Filaments of line-emitting gas may condense out of the general flow through thermal or radiation driven instabilities, as has been discussed by other authors. Because the crossing time for material in the broad line region is $\sim 10^2$ years, and the efficiency of accretion during the wind phase is $\lesssim 10^{-3}$, the wind need not operate for more than one per cent of the time. Indeed, if the corresponding accretion occurred continuously, the black hole would double its mass in less than 10^5 years. More plausibly, the eruption of the wind shuts off the supply of mass to the torus, which slowly drains until another burst of rapid accretion and wind generation occurs. A quasar undergoing a windy episode may be marked by an anomalously soft spectrum, though not by a significantly different luminosity. Statistically, one might expect several of the known quasars to be in a windy phase, although this would not be the case if the broad emission lines tended to be weak during these periods. In between windy episodes, the spectrum of the torus may be considerably harder, and could be partially responsible for exciting the lines. However, it is likely that much of the photoionizing radiation is supplied by the jets, which would persist during the windy phases.

In summary, the properties of the broad line regions in quasars and Seyferts may provide a sensitive probe of gasdynamical conditions on much smaller scales, where tori regulated by nuclear reactions may be responsible for producing the observed VLBI jets. A more detailed report on this research will appear elsewhere.

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