THE ACTIVE REGION IN GALACTIC NUCLEI : AN OUTLINE

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The activity of galactic nuclei entails a continuous release of energy in the form of hot gas, violent motions, relativistic particles and ordered magnetic fields. The spectrum radiated spans most of the electromagnetic band, from radiowaves to γ-rays, and the power can reach or exceed $10^{44} - 10^{46}$ ergs sec^{-1}. Various extensive surveys dealing with this subject have been published recently (see, e.g., Hazard and Mitton 1979; Physica Scripta 1978; Setti 1976; Wolfe 1979): we refer the reader to these publications for details. In the following we shall just outline the main ideas which are being discussed to explain the origin of these phenomena which pose one of the most important problems of modern astronomy.

1. In many sources one observes outbursts: the timescale involved implies a size of the emitting region $d \lesssim c\tau$ (this does not hold for sources moving relativistically, Rees 1967). Even before the advent of VLBI one had therefore learned that compact variable radiosources in nuclei of galaxies have a size $10^{18} - 10^{19}$ cm. The characteristics of their emission imply magnetic fields $10^{-3\pm1}$ gauss and the presence of electrons with Lorentz factors up to $\gamma \sim 10^3 - 10^4$. The total energy content has been estimated in the range $10^{52} - 10^{56}$ ergs or so, with many underlying uncertainties. The radioemitting volume could radiate high energy photons because of the inverse Compton process, and it is important to monitor the X-ray flux in order to find possible changes correlated with the activity of the compact radiocomponents.

However, the frequent existence of variability in the optical and in the X-ray range with a much faster timescale ($\sim$ hours) suggests that most of the high frequency continuum comes from a smaller region,

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some $10^{14}-10^{15}$ cm across. This is not much larger than the gravitational radius of a system with $M \sim 10^8$ $M_\odot$ and indeed it is generally believed that active nuclei are powered by the release of gravitational energy from collapsed objects.

The models proposed invoke either the presence of a single massive body or a dense cluster of stars (normal or collapsed). The occurrence of outbursts involving much more than the energy released in the explosion of single stars argues in favor of massive objects. In addition, there seems to be a preferred orientation in the geometry and in the polarization properties of successive outbursts (see Wolfe 1979): again this suggests a coherent structure for the central engine.

The mechanisms considered to release gravitational energy are either the infall of matter into a central object (accretion models) or the output of energy in the form of large scale electromagnetic fields from the magnetosphere of rotating supermassive objects (electrodynamic outflow models). Both mechanisms can work in principle and indeed - inside our own galaxy - they are responsible for the existence of compact X-ray sources and of pulsars. The main difference between them is that accretion is basically a thermal phenomenon while the presence of coherent electromagnetic fields naturally leads to the production of non-thermal particles. In real life, however, the difference is not always clear: for instance, in the case of accretion the presence of magnetic fields embedded in the falling gas could lead to non-thermal aspects (acceleration of particles, flares ...). Apart from that, it is still unclear whether the high frequency emission in galactic nuclei results from the presence of hot gases or whether it is genuine synchrotron and/or inverse Comption radiation. In principle, the best possibility to distinguish between accretion and electrodynamic outflow lies in the existence of the Eddington limit for spherical accretion: for an object $M \sim 10^7 - 10^8$ $M_\odot$ this entails $L \lesssim 10^{45} - 10^{46}$ ergs sec^{-1} and an infall rate $\sim 0.1 - 1$ $M_\odot$ $year^{-1}$ (we assume an efficiency ~ 10 %). Although one may conceive accretion models which violate the Eddington limit by invoking special geometrical constraints, the evidence from compact X-ray sources in our own galaxy shows that in general this is not the case. The existence of many extragalactic objects exceeding the above limit would therefore represent evidence for electromagnetic outflow instead of accretion (some examples already exist: 3C 273 reaches 10^{47} ergs sec^{-1} in the γ-ray range; NGC 1068 has a far infrared output in the range $10^{47} - 10^{48}$ ergs sec^{-1}, etc.). Both types of models can be applied either to SM stars or to black holes. In the case of electrodynamic outflow the nature of the underlying object is irrelevant: a black hole surrounded by a magnetized accretion disk behaves similarly to a classical magnetized supermassive object or spinar (Blandford and Znajek 1977). From an observational point of view many recent claims for the discovery of black holes in galactic nuclei (such as M 87) are misleading: they just show the presence of a mass concentration in the nuclear region, irrespective of whether the central object is a black hole, a SM star or even a dense star cluster. Because of this reason, in the following we shall treat the central engine as a BLACK BOX rather than a black hole or a spinar and concentrate on those aspects of the electrodynamic model which are independent from the particular nature of the central body.

2. It is well known that in most cases the physical parameters in the central region of active nuclei entail very fast radiative losses and require either a continuous reheating of the gas or - in the case of non-thermal processes - a continuous acceleration of particles. In the latter case this could be realized either by injecting new particles or by stirring continuously the same ones. The first scenario leads to the expectation of a large number of "dead" particles which would depolarize the radiation because of the Faraday effect. This contradicts the observations and one should therefore assume that the dominant process involves re-acceleration in situ of pre-existing electrons.

This requirement is naturally incorporated in the electrodynamic outflow models discussed recently by Pacini and Salvati (1978) and by Cavaliere and Morrison (preprint 1979). Basically, one assumes that in the central part of galactic nuclei the black box contains a spinar or a black hole surrounded by large scale electromagnetic fields where the acceleration and the radiation processes are equally fast. The particles can reach a maximum energy γ_{max} such that the losses (proportional to γ^2) inhibit the possibility of further gains. The flux of the Poynting vector from the black box is $L_{em} \sim B^2R^2c$ (R is the size of the region under consideration) and it is equal to the total non-thermal luminosity L of the active nucleus. It is easy to see that the problem of the physical conditions in the emitting region becomes unusually well defined. If one knows observationally the synchrotron luminosity L, the band where this power is radiated ν and the size of the emitting region R, one can determine univocally the physical parameters in the source. For a source with $R \sim 10^{15}$ cm, emitting $L \sim 10^{45}$ ergs sec^{-1} in the IR-optical band via the synchrotron process, the electrodynamic model requires $B \sim 10^2$ $\gamma \sim 10^2 - 10^3$ (Pacini and Salvati 1978). In the simplest homogeneous model the flux carried by the field causing the synchrotron emission is obviously of the same order as the flux carried by the primary synchrotron photons. Since the respective energy densities are roughly equal $u_\gamma \sim u_B$, the Compton output should be of the same order as the synchrotron output. We note that this is in good agreement with the observational evidence for an X-ray luminosity of active nuclei roughly comparable to the IR-optical luminosity (see other contributions in this same Joint Discussion).

As an example we can consider the nucleus of NGC 1275. Night-to-night variations in its optical continuum have been reported by various authors and imply an emitting region $R < 10^{16}$ cm with a total power $L \sim 10^{44}$ ergs sec^{-1}. Geller et al. (1979) have recently discussed a model based upon the assumption that the IR-optical emission has a synchrotron origin while the compact X-ray source arises from inverse Compton scattering. Standard considerations imply then a magnetic field strength $B \sim 10^2$ gauss, $\gamma \sim 10^2 - 10^3$ and a formal lifetime for the radiating particles $\lesssim 10^2$ sec. As noted by the authors, this requires a continuous re-acceleration process: the electrodynamic outflow model takes care of this difficulty because the flux of the Poynting vector B^2R^2c continuously replenishes the energy radiated away.

An investigation of the formation of the particles energy spectrum in the framework of the electrodynamic model should take into account the condition "gains equal losses" for each particle in the large scale electromagnetic field. Such a condition entails that particles reach different energies at different distances from the central object: a detailed discussion of this problem is now being prepared (Pacini and Salvati 1979).

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