BAR INSTABILITIES AND NUCLEAR ACTIVITY IN DISK GALAXIES

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ABSTRACT. A mechanism for fueling active galactic nuclei and nuclear starburst galaxies is suggested. It consists of two stages. First, a large-scale stellar bar sweeps the ISM into a gaseous disk of a few hundred pc radius. This disk may, under certain conditions, become dynamically unstable, induce radial flow, and feed viscosity-driven accretion flow around a black hole. It may lead to the formation of a black hole if none was present initially.

The problem of fueling active galactic nuclei (AGNs) poses a challenge both for theoreticians and observers. Local sources of accreting material suggested so far, e.g., tidal disruption of stars by a central supermassive black hole (SBH) and stellar collisions, suffer from various drawbacks. Extreme stellar densities and/or efficient accretion of the stellar debris are required to power luminous AGNs, in the above context. Alternatively, viscous processes seem to be inefficient in redistributing the angular momentum on scales larger than ~ 10 pc in a cold gas, $\sim 100T_2$ (Shlosman and Begelman, 1988). In a continuous fluid disk, the parameter α is likely to be $\lesssim 1$, as larger values would imply supersonic turbulence and lead to rapid dissipation. In a fragmented disk (e.g., due to the effects of self-gravity), the efficiency of angular momentum transfer depends upon the cloud-cloud collision time scale, $t_{\rm coll}$, and the effective $\alpha \sim t_{\rm dyn}/t_{\rm coll}$, where $t_{\rm dyn}$ is the orbital time at the distance r. We expect $\alpha \lesssim 1$ at the onset of fragmentation and to decrease if the clouds contract further. If the stellar potential dominates over the potential of the SBH, the shear is reduced, the viscous inflow time is prolonged and exceeds the Hubble time. Standard viscous processes, therefore, cannot play a role in collecting gas, liberated in the main body of the host galaxy, and bringing it towards the SBH. Although magnetic fields in principle are capable of removing the excess angular momentum, no observational evidence exists up-to-date of large scale fields in AGNs. Tidal effects of companion and/or passing-by galaxies may under certain conditions induce inward gas motions, down to scales ~ 1 kpc. But unless some additional mechanism operates, this gas will have plenty of time to cool and form stars, hence leading to a starburst galaxy rather than an AGN (Shlosman *et al.* 1988). Also, Seyferts probably *do not* have an excess of close companions of comparable size, in contradiction to an earlier survey (Fuentes-Williams and Stocke, 1988).

The association of barred spirals and Seyferts prompted Simkin *et al.* (1980) to speculate that the enhanced gas inflow in barred galaxies somehow leads to the AGN phenomenon. To support this view, hydrodynamical studies of the response of a compressible fluid to an imposed non-axisymmetric distortion of the potential showed that under certain conditions, the gas flows through a pair of shocks and loses its angular momentum in some ten rotation periods. Notice that observations show that both the total CO and H_2 content and the ratio of molecular gas to HI, peak at Hubble types Sb – Sbc, thus correlating with thermal and/or nonthermal activity.

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Despite its attractiveness, the idea of a large-scale bar *solely* responsible for the nonthermal activity in the nucleus of a host galaxy cannot be sustained. Firstly, the inflow generated by a barred rotating potential does not extend all the way into scales where turbulent viscosity could take over. Secondly, about half of all spirals are barred (or at least ovally distorted), whereas only a few percent of them show pronounced AGN activity. We suggest here that a gas accumulated in the inner few $\times$ 100 pc as a consequence of the flow in the large-scale *stellar* bar, becomes dynamically unstable again and forms a *gaseous* bar. Thus by having bars on different scales, i.e. bars within bars, it becomes possible to force feed the viscosity-driven flow at scales $\sim$ 10 pc. A barred spiral host galaxy seems to be *necessary but not sufficient* for a Seyfert nucleus to develop.

For a variety of reasons the gas flow in a barred potential slows down at a radius $\sim$ 0.1 of the bar radius. It may, however, get stuck at larger radii, if Inner Lindblad Resonances are present. Despite the absence of a single criterion for global stability of self-gravitating disks, the semi-empirical criterion proposed by Ostriker and Peebles (1973) is useful for a large variety of models. Its application to a three-component system consisting of a gaseous disk embedded in a stellar disk and a halo results in stringent limits on the mechanism proposed here. If the gas was initially distributed with the same radial length as the stellar disk and contributed, say, $\sim$ 20% of the total mass, then a reduction of sise of the gas disk by a factor $\sim$ 10 would make it vulnerable to global instabilities. Because gaseous disks have fewer degrees of freedom than stellar disks, they are also more stable dynamically. However, if a gaseous disk consists of clouds with a rather low filling factor, the collision frequency of clouds is small enough compared to the orbital frequency and the system will behave more like a stellar disk.

We find that a stellar bar sweeping the gas inwards would yield a disk which can go unstable if it is not too hot. The unstable configuration is likely to resemble a bar-driven spiral, which will transfer angular momentum and lead to further contraction. To the extent that the system does not form stars, the inevitable consequence of the gaseous system sinking towards the center of the stellar system is that the former will become increasingly unstable. Massive star formation may modify the subsequent evolution of the system and determine whether the principal form of activity is a starburst or an AGN. The passage of a close companion may induce a stellar bar, but this is not necessary, as isolated galaxies host bars which are relics of galaxy formation.

We predict that some evidence of dynamical instabilities on scales $\sim$ 100 pc must be present in the central regions of active galaxies. The Sérsic-Pastorisa galaxies with unusually bright and disturbed nuclei may be a good example. *All* of these galaxies are barred and some are Seyferts and starbursts. More high resolution optical and infrared observations of these objects, and HI and CO observations of the innermost regions of moderately distant AGNs are desirable.

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DISCUSSION

G. BURBIDGE You have given an excellent account of the problems associated with the idea that accretion is the energy generating process. Why not go the whole way and consider the possibility that accretion is *not* responsible for what we see?

SHLOSMAN The accretion process is unimportant on the galactic scale ($\sim$ kpc). It may, however, be the dominant process in the innermost parts of AGNs ($\sim$ pc). Accretion disks are observed, in fact, in many galactic compact sources. The present situation, with no direct observational evidences for disks in AGNs is still inconclusive. This matter will be probably clarified in the near future.

ROOS I would like to point out that the numbers of stars that are tidally disrupted near a massive hole in the nucleus of a galaxy could become larger by several orders of magnitude if the star distribution around the hole was perturbed for instance by a galaxy merger. This increase occurs when the nuclei of the merging galaxies are separated by $\sim$ 1-10^3 pc. The outer parts ($>$ 1 kpc) of the galaxy would still show distortions due to the tidal interaction of the two galaxies. So, activity of the nucleus and non-axisymmetric distortions could both be caused by a merger event.

SHLOSMAN I think the effect that the mergers can have (in their late stage) on the filling up of the loss cone must be carefully checked.

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