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SMBH spherically symmetric accretion regulated by violent star formation feedback

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Abstract. The mounting evidence for violent nuclear star formation in Seyfert galaxies has led us to consider the hydrodynamics of the matter reinserted by massive stars through strong stellar winds and supernovae, under the presence of a central massive BH. We show that in all cases there is a bimodal solution strongly weighted by the location of the stagnation radius (R_{st}), which splits the star cluster into two different zones. Matter reinserted within the stagnation volume is to be accreted by the BH while its outer counterpart would composed a star cluster wind. The mechanical power of the latter, ensures that there is no accretion of the ISM into the BH and thus the BH accretion and its luminosity is regulated by the star formation feedback. The location of the stagnation radius is a function of three parameters: the BH mass, the mechanical power (or mass) of the star formation event and the size of the star forming region. Here we present our self-consistent, stationary solution, discuss the accretion rates and BH luminosities and show that our model predicts the intrinsic link between the BH activity and the starburst parameters.

Key words. accretion — galaxies: active — galaxies: starburst — galaxies: star clusters — hydrodynamics

1. Introduction

The imprints of massive starbursts around the central supermassive black hole (BH) have been revealed in a number of Seyfert galaxies. Levenson et al. (2001), Jiménez-Bailón et al. (2005) found that in many cases the spectral fit to the X-ray emission from Seyfert galaxies requires a complementary thermal component associated with an extended starburst. Alexander et al. (2005) provided ultra deep Chandra observations of 20 radio-selected submillimeter-emitting galaxies selected from the deep SCUBA surveys and combined this with Keck deep spectroscopy. They found strong evidences that a substantial fraction ($\sim$ 75%) of the selected star forming galaxies harbor also an active galactic nucleus (AGN). They also found the average X-ray to the far-IR luminosity ratio an order of magnitude smaller than that in the case of a typical quasar (QSO). This led them to conclude that vigorous star formation activity ($\sim$ 1000 $M_\odot$ yr^{-1}) dominates the bolometric luminosity of their AGN-classified sources and that submillimeter-emitting galaxies are associated with a massive black hole (BH) and stellar component rapid growth stage which ends up with the emergence of an un-obscured quasar.

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Heckman et al. (1997) and González Delgado et al. (1998) found absorption line features associated with photospheres of O and B stars and their stellar winds in the ultraviolet and optical spectra of four Seyfert 2 galaxies that presented direct evidence for the existence of nuclear starbursts in the AGN galaxies.

Terlevich et al. (1990) proposed to use the Ca II triplet as the near-IR indicator of star formation in AGN galaxies. Schweitzer et al. (2006) detected the polycyclic aromatic hydrocarbon (PAH) features, associated with soft UV radiation emerging from the star forming region, in 11 from 26 selected quasars. They found that at least 30% but likely much more of the far-IR luminosity in their sample QSOs arises from star formation and concluded that there is a strong connection between the AGN and starburst activity in the QSOs. These results have been confirmed in Netzer et al. (2007) who presented the supplementing spectral energy distributions.

Seth et al. (2007) presented evidences on the presence of super massive black holes in galaxies which host compact nuclear star clusters. Many of these galaxies present a mixed AGN-starburst optical spectra and are classified as composite.

Strong evidences for intense high velocity outflows in the composite Seyfert 2/starburst ultra luminous infrared galaxies have been presented and thoroughly discussed in González Delgado et al. (1998) and Rupke et al. (2005).

Thus star formation occurs at different space and energy scales around the SMBH in many AGN galaxies and QSOs. The mechanical power of young nuclear starbursts might prevent through the cluster winds the accretion of interstellar matter from the bulges and disks of their host galaxies onto the central BHs (see, for example, McLaughlin et al. 2006). Here we show that in such cases the BHs are fed with the matter injected by numerous stellar winds and SNe explosions that result from the multiple evolving sources. This implies that nuclear starbursts must strongly affect and even control the power of the central BH at the stage of vigorous star formation. In fact, it may be the dominant factor to be consider in order to understand the physics of the BH growth and the relation between the BH and star burst luminosity in AGN galaxies and QSOs.

2. The model

We assume that massive stars are homogeneously distributed inside a spherical volume of radius R_{SC} and that the mechanical energy deposited through stellar winds and supernovae, L_{SC}, is thermalized via random collisions of the gaseous streams from neighboring sources. This results into a high temperature and a high thermal pressure that drives a high velocity ($u \sim 1000$ km s^{-1}) outflow of the injected matter.

However in presence of a massive central black hole, a fraction of the deposited matter is to remain bound inside the cluster to eventually fall onto the central BH. The outer zones, where the star burst wind is formed, and the central accretion zone are separated by the stagnation radius, R_{st}, where the expansion velocity, $u = 0$ km s^{-1}. The position of the stagnation point is an important issue because it defines both the accretion rate onto the central BH, and the amount of matter that the star forming region returns to the host galaxy interstellar medium. This is defined by the two boundary conditions (see Silich et al. 2008). Specifically, the outer and inner sonic points (the points where the speed of the flow is equal to the local sound speed) must be located at the star cluster surface and in the star cluster center, respectively. Figure 1 presents a schematic representation of our model.

3. Accretion rates and BH luminosities

Silich et al. (2008) found that the accretion rate and the luminosity of the BH located at the center of a young stellar cluster depend on the BH and star cluster mass and on the size of the star forming region. There is a surface in this 3D parameter space which separates clusters evolving in the stationary regime from those which cannot fulfill stationary conditions. Figure 2 presents the threshold mechanical luminosity for stellar clusters with a 10^8 M$_\odot$ central BH.

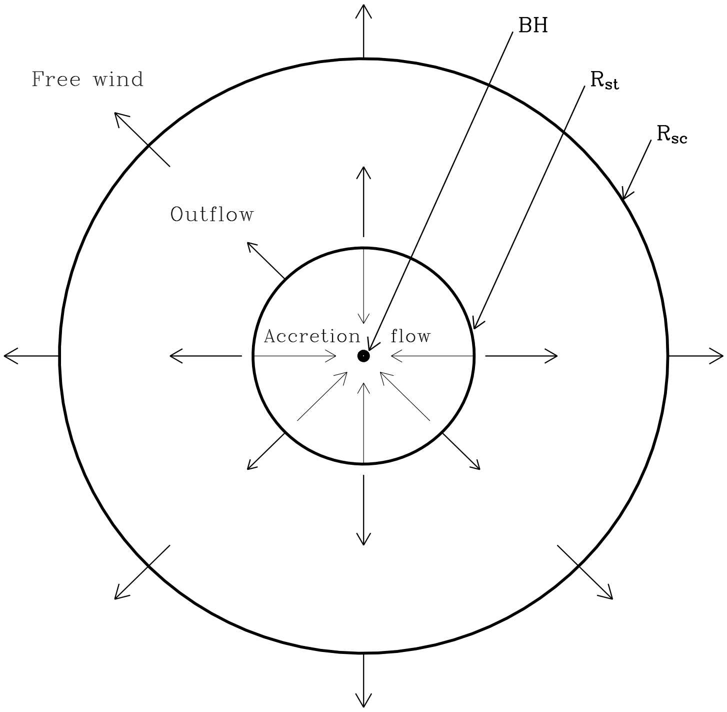

Fig. 1. The structure of the flow that results from the thermalization of the supernova ejecta and stellar winds inside a star forming region with a massive black hole at the center. The radii of the internal and the external circles represent the stagnation radius R_{st} and the star cluster radius R_{sc}, respectively. The arrows indicate the direction of the flow. The black dot at the center marks the location of the black hole.

Clusters whose mechanical luminosity (and mass) exceeds the critical value cannot form a stationary outflow. The thermalized plasma inside such clusters is thermally unstable, presents a complicated velocity pattern and is expected to be re-processed into new generations of stars (Wünsch et al. 2008).

Clusters whose mechanical luminosity is smaller than the critical value, compose stationary accretion flow in the central zones and form stationary outflows in the outer zones of the cluster. The accretion luminosity of a 10^8 $M_\odot$ BH located at the center of such clusters is presented in Figure 3. It is instructive to note that the BH luminosity can approach the Eddington limit only in the case of very compact stellar clusters whose radii are smaller than the critical value, R_{crit}, marked in Figure 2 by a vertical line.

4. Conclusions

Here we discuss the link between the supermassive BH activity and star formation in the central zones of AGN galaxies and QSOs. We briefly formulate the input physics and major results from our (Silich et al. 2008) self-consistent, stationary, spherically symmetric solution for gaseous flows which are formed inside starburst regions with a central supermassive BH.

We show that the thermalization of the kinetic energy released by massive stars inside young stellar clusters results into a bimodal solution with an accretion of the injected matter onto a central BH in the inner zones of the cluster, and a fast outflow of the returned matter from the outer zones of the star forming region.

Our model predicts the intrinsic link between the BH activity and parameters of the

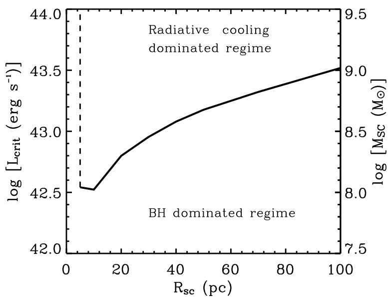

Fig. 2. The threshold mechanical luminosity for a star cluster with a 10^8 M$_\odot$ BH at the center. The stationary solution exists only below the threshold line. Above the threshold line the thermalized plasma inside the cluster is thermally unstable and the flow has very complicated time-dependent velocity pattern. The vertical dashed line marks the critical radius, R_{crit}. Cooling cannot compete with gravity and the stationary solution always exists if the star cluster radius, $R_{SC} < R_{crit}$.

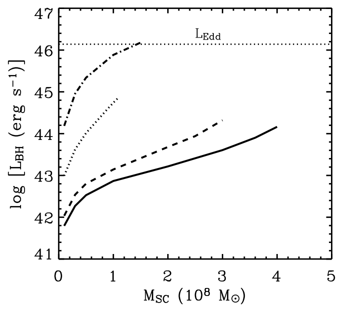

Fig. 3. The BH accretion luminosity. The accretion luminosity of a 10^8 M$_\odot$ BH embedded into progressively more compact clusters. Solid, dashes, dotted and dash-dotted lines present the results of the calculations for star clusters whose radii are R_{SC} = 40 pc, R_{SC} = 30 pc, R_{SC} = 10 pc and R_{SC} = 3 pc, respectively. The horizontal dotted line displays the Eddington limit. The last point on every line displays the BH accretion luminosity when the star cluster reaches the threshold line. In the case of very compact (R_{SC} = 3 pc) star cluster we stopped our calculations when the BH luminosity reaches the Eddington value.

starburst region. Specifically, we show that the BH luminosity, L_{BH}, depends on the mass and size of the stellar cluster hosting a BH. It grows with mass of the cluster and is larger in the case of more compact clusters. In the case of extended starbursts, the BH luminosities fall well below the Eddington limit. However, L_{BH} approaches the Eddington value in the case of very compact star forming regions.

Recent results dealing with far-IR emission of QSO and spectral properties of SCUBA galaxies suggest that a continuous mode of star formation is relevant in order to understand the intrinsic links between AGNs and star formation activity. This will be a subject for our forthcoming communication.

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