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FUELING-CONTROLLED THE GROWTH OF MASSIVE BLACK HOLES

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RESUMEN

Estudiamos la relación entre los agujeros negros nucleares de alta masa y el potencial gravitatorio de la galaxia anfitriona. Utilizando simulaciones numéricas de malla adaptativa (AMR) analizamos cómo el gas es transportado a las regiones nucleares (kpc central) de las galaxias. Estudiamos el gas alimentando el disco de acreción interior (escala sub-pc) y la formación estelar en un disco nuclear masivo como aquellos encontrados en proto-esferoides (ULIRGs, galaxias SCUBA). Estas simulaciones a escala de sub-pc, en las que el gas energiza al disco, y se va agotando por la formación estelar, satisfacen de forma natural la relación '$M_{\rm BH} - M_{\rm virial}$', con una dispersión considerablemente menor a la observada. Encontramos que se cumple una versión generalizada de la Ley de Kennicutt-Schmidt para los brotes de formación estelar, en la cual la tasa de agotamiento total del gas ($\dot{M}_{\rm gas} = \dot{M}_{\rm BH} + \dot{M}_{\rm SF}$) escala como $M_{\rm gas}/t_{\rm orbital}$. Ver Escala (2007) para más detalles sobre este trabajo.

ABSTRACT

We study the relation between nuclear massive black holes and their host spheroid gravitational potential. Using AMR numerical simulations, we analyze how gas is transported into the nuclear (central kpc) regions of galaxies. We study gas fueling onto the inner accretion disk (sub-pc scale) and star formation in a massive nuclear disk like those generally found in proto-spheroids (ULIRGs, SCUBA Galaxies). These sub-pc resolution simulations of gas fueling, which is mainly depleted by star formation, naturally satisfy the '$M_{\rm BH} - M_{\rm virial}$' relation, with a scatter considerably less than that observed. We find that a generalized version of the Kennicutt-Schmidt Law for starbursts is satisfied, in which the total gas depletion rate ($\dot{M}_{\rm gas} = \dot{M}_{\rm BH} + \dot{M}_{\rm SF}$) scales as $M_{\rm gas}/t_{\rm orbital}$. See Escala (2007) for more details about this work.

Key Words: black hole physics — galaxies: formation — quasars: general

1. INTRODUCTION

In the past years, it has been found that most nearby massive spheroids (elliptical and spiral bulges) host nuclear massive black holes (MBH) (Kormendy & Richstone 1995), whose masses correlate with their host spheroid properties. Two correlations arise as the more relevant links between MBH and their hosts. First, the black hole mass correlates with host mass ('$M_{\rm bh} - M_{\rm bulge}$' relation; Marconi & Hunt 2003). Second, their masses correlate with the average random velocities of the stars in their host ('$M_{\rm bh} - \sigma$' relation; Ferrarrese & Merritt 2000; Gebhardt et al. 2000).

The study of MBH growth by gas accretion is usually focused on the study of accretion disks. However, these accretion disks are Keplerian by nature and therefore have negligible masses compared to that of the MBH. They must be continuously replenished, otherwise the mass of the MBH will not have considerable growth. The key question in the growth of MBHs by accretion is how to remove the large angular momentum of gas in a galaxy in order to funnel it into the accretion disk in the central sub-pc region — the so called 'Fueling Problem'.

There are several mechanisms for fueling gas into kpc scales, such as galaxy mergers/interactions, bars and resonances. Gravitational torques in galaxy mergers arise as the dominant process for transporting large amounts of gas down to the central few hundred parsecs and for triggering most of the MBH growth. In a merger, after a violently relaxed core is formed at the center, most of the gas will settle in a nuclear disk (typically several hundred parsecs in diameter) that is rotationally supported against the overall (gas + stars) gravitational potential (Mayer el al. 2007). The MBHs will migrate to the center, and merge on a timescale relatively short compared to the lifetime of the nuclear disk (Escala et al. 2004, 2005; Dotti et al. 2006). In this paper, this massive nuclear disk, along with a central MBH, is the starting point of our study. We focus on the mass fueling onto the inner accretion disk around a MBH (from the few hundred pc down to sub-pc scale).

2. MASS TRANSPORT IN GALACTIC NUCLEI

In a previous work, Escala (2006, hereafter E06), we analyzed how gas is expected to be transported

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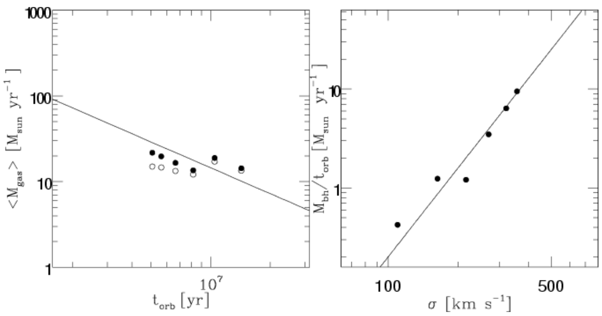

Fig. 1. Left: Average gas depletion rate $<\dot{M}_{\rm gas}>$ as a function of the orbital time, for the six different runs. The open circles are the gas depletion rate due to only star formation, the filled circles are the gas depletion rate due to both star formation and accretion onto the MBH. The solid line corresponds to $<\dot{M}_{\rm gas}>\propto t_{\rm orb}^{-1}$. Right: Total mass accreted by the MBH per orbital time (filled circles) plotted against the stellar velocity dispertion σ, for the different runs. The solid line corresponds to $M_{\rm BH}/t_{\rm orb} \propto \sigma^3$.

into the nuclear regions of galaxies using simple analytical models. E06 showed that the average mass fueling onto the inner accretion disk, $<\dot{M}>$, is proportional to σ^3 (equation 3 in E06). E06 also coupled this result with the expected gas lifetime given by the Kennicutt-Schmidt Law (Kennicutt 1998; $t_{\rm gas} \approx t_{\rm SF} = \Sigma_{\rm gas}/\dot{\Sigma}_{\rm SF} \propto t_{\rm orb} = R_{\rm d}/\sigma$), leading naturally to the '$M_{\rm BH} - M_{\rm virial}$' relation:

$$M_{\rm BH} = \dot{M}\, t_{\rm gas} \propto R_{\rm d}\sigma^2 \propto M_{\rm virial}\,. \qquad (1)$$

In this work, we verify whether each of these conditions are satisfied in more realistic AMR simulations. We performed six different runs in which we varied the mass of the bulge in such a way that the velocity dispersion of the bulge, σ, is: 110, 163, 216, 270, 321 and 357 km s^{-1} (see Escala 2007 for more details).

We start by investigating whether the star formation rate in our model satisfies the Kennicutt-Schmidt Law: $\dot{\Sigma}_{\rm SF}/\Sigma_{\rm gas} = \dot{M}_{\rm SF}/M_{\rm gas} \propto t_{\rm orb}^{-1}$. Figure 1a shows the average gas depletion rate, $<\dot{M}_{\rm gas}>$, against the orbital time ($= 2\pi R_{\rm d}/\sigma$) for the six different runs. Since the total gas mass $M_{\rm gas}$ is the same for all the runs, the Kennicutt-Schmidt Law predicts that $<\dot{M}_{\rm gas}>$ must be proportional to $1/t_{\rm orb}$, as indicated by the solid line in Figure 1a. The open circles are the gas depletion rate including only the gas depleted by star formation described by in the Kennicutt-Schmidt Law. The filled circles are again the gas depletion rate for each simulation, but now including the gas depleted by star formation and by accretion onto the central black hole. The figure

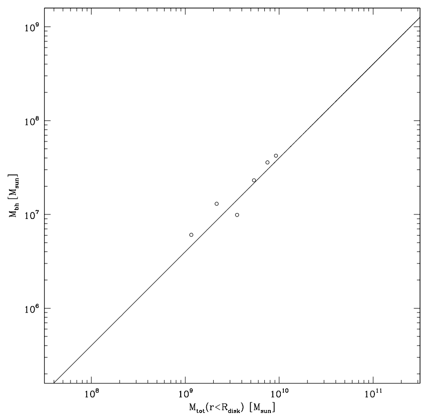

Fig. 2. Final MBH mass plotted against the total dynamical mass ($M_{\rm gas} + M_{\rm star}$) enclosed within the initial disk, for the six different runs (circles). The solid line corresponds to $M_{\rm BH} \propto M_{\rm tot}$.

clearly shows that it is the total gas depletion rate that correlates best with the inverse of the orbital time $t_{\rm orb}$, and not the gas depletion rate due to star formation only.

The second condition needed to be satisfied by our simulations is that $<\dot{M}>$ is proportional to σ^3, something that was already tested in E06 for an adiabatic disk. We estimated $<\dot{M}>$ by the mass accretion rate onto the sink particle per orbital time $M_{\rm BH}/t_{\rm orb}$. Figure 1b shows $M_{\rm BH}/t_{\rm orb}$ as a function of σ, where the filled circles are the mass accretion rate onto the BH per orbital time for the different runs, and the solid line is $<\dot{M}>\propto \sigma^3$. Thus, the condition $<\dot{M}>\propto \sigma^3$ is also satisfied in our simulations.

Finally, we plot the final MBH mass for the six different runs in Figure 2. In each run, the host spheroid has a different mass and therefore a different total dynamical mass ($M_{\rm star} + M_{\rm gas}$) enclosed within the initial disk. Figure 2 shows a clear correlation between the MBH mass and the host spheroid mass. The solid line is $M_{\rm bh} \propto M_{\rm tot}$ and the rms scatter is 0.104 dex (less than in the '$M_{\rm BH} - M_{\rm virial}$' relation).

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