GAS KINEMATIC MEASUREMENTS OF BLACK HOLE MASSES IN SPIRAL GALAXIES

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INTRODUCTION

Supermassive Black Holes (MBH, \(10^6-10^9 M_{\odot}\)) are detected in nearly all galaxy nuclei, and the masses are tightly correlated with mass, luminosity, and stellar velocity dispersion of the host spherical (Ferrarese & Merritt 2000). This indicates a tight link between galaxy formation and evolution and BH growth. It is therefore extremely important to study the relations between BHs and their hosts by measuring the velocity dispersion of MBH in spherical galaxies, and enlarging their number. However, most of the \(\sim 10^7-10^8 M_{\odot}\) BH masses are in early type galaxies and the number of spiral galaxies is small (Kormendy & Ford 2005). It is clearly mandatory to increase this number in order to understand how common MBH are in spirals and if they follow the same correlations as early type galaxies. Even constraining upper limits on \(M_{\odot}\) could be considered as a significant improvement given the scatter of measurements and the difficulties in performing the required observations in spiral galaxies. Moreover, MBH mass correlations are studied only in the \(10^8-10^9 M_{\odot}\) mass range and it is expected that spiral galaxies might host lower mass black holes below \(10^6 M_{\odot}\). For these reasons, we have undertaken a spectroscopic survey of 34 spirals using the Space Telescope Imaging Spectrograph (STIS) on HST (P. D. Anton). In all cases, spectra were obtained with the aim of studying the kinematics of the gas in the circumnuclear region in order to estimate MBH masses. Earlier results on BH mass measurements from this project have been published by Marconi et al. (2004) and Malkan et al. (2005).

GAS KINEMATIC METHOD ON SPIRAL GALAXIES

Here we present new Space Telescope Imaging Spectrograph (STIS) observations of three early-type spirals: NGC 3130, NGC 3310, and NGC 3486. The bright optical emission lines Hα, Hβ, [NII] λλ 6548,6583 Å and [SII] λλ 6716,6731 Å were used to study the kinematics of the ionized gas in the nuclear regions of each galaxy with a \(0.3-0.7^\prime\) spatial resolution. Our STIS data for NGC 3486 were analyzed in conjunction with archival ones to compare the gas kinematical estimate of the black hole mass from the accurate data from Hα, Hβ, [SII] measurements with the accurate data from Hα, [NII] measurements (M. S. Kormendy et al., 2003; M. S. Kormendy et al., 2003). For each galaxy we obtained spectra at three parallel positions with the central slit centered on the nuclear region, and flanking offsets by \(0.2^\prime\). These different positions, for NGC 3310, are shown in Fig. 1A, and are labeled NUC, OFF1, and OFF2. For each slit position we modeled the line profiles with the expansion of 

To reproduce the gas kinematic data, we assumed that the ionized gas is rotating in a disk placed in the principal plane of the galaxy potential (see Marconi et al., 2004). To account for the instrumental effects, we computed the observed moment of the line profile at each position with the model. In Fig. 2B we show the average velocity \(\sigma\) vs \(M_{\odot}\) for the three galaxies. The weight of the average profile is the observed surface brightness distribution of the emission line. Since \(v(\sigma)\) \(\sim \sigma\), the inclination of the ionized gas disk cannot be treated as a free parameter. We have used an initial fixed value of \(i_{\odot}\) and then we investigated the effects of varying the best fitted parameters.

In Fig. 2 we have presented the dynamical modeling of the three rotation curves. We first worked with an initial fixed value of inclination and then we found the range of possible values for \(M_{\odot}\) taking into account the allowed values of inclinations. Previous work on spiral galaxies have made the simplifying assumption that the nuclear gas disks used for MBH detection have the same inclination as large scale galactic disks. In fact, in contrast to elliptical galaxies, it is not possible to determine the disk inclination and inclinations from HST images of spiral galaxies. In this work we have considered the effects of the unknown inclination which results in a range of \(M_{\odot}\) values at upper limits. The \(M_{\odot}\) values derived for a given disk inclination are characterized by statistical errors but the same \(M_{\odot}\) values vary as \(\sin^2(\theta)\).

\(\rightarrow\) The observed rotation curves of NGC 3310 within the inner \(0.05-0.08^\prime\) from the nucleus \(\langle P \leq 0.50\rangle\) agree very well with a circularly rotating disk model. However, the spatial resolution of the observations only allowed us to set an upper limit to the BH mass, \(M_{\odot} \geq 1.0 \times 10^6 M_{\odot}\), for a disk inclination of \(70^\circ\). When taking into account the allowed disk inclination \((0.05 \leq 0.80^\prime)\), \(M_{\odot}\) varies in the range of \(3 \times 10^6 M_{\odot}\). \(4 \times 10^6 M_{\odot}\). The agreement with a circularly rotating disk model does not allow to consider this detection completely reliable. The allowed disk inclination values are taken into account in the range \((0.05 \leq 0.80^\prime)\), \(M_{\odot}\) varies in the range of \(3 \times 10^6 M_{\odot}\). \(4 \times 10^6 M_{\odot}\).

\(\rightarrow\) In NGC 4380 the rotation curves require the presence of a black hole with mass \(M_{\odot} = 5 \times 10^6 M_{\odot}\) for a disk inclination of \(70^\circ\). When taking into account the allowed disk inclination \((0.05 \leq 0.80^\prime)\), \(M_{\odot}\) varies in the range of \(3 \times 10^6 M_{\odot}\). \(4 \times 10^6 M_{\odot}\). The agreement with a circularly rotating disk model does not allow to consider this detection completely reliable. The allowed disk inclination values are taken into account in the range \((0.05 \leq 0.80^\prime)\), \(M_{\odot}\) varies in the range of \(3 \times 10^6 M_{\odot}\). \(4 \times 10^6 M_{\odot}\).

\(\rightarrow\) In NGC 4382 the simultaneous modeling of our and archival data constrains the BH mass to \(M_{\odot} = 3 \times 10^6 M_{\odot}\) for a disk inclination of \(60^\circ\). When taking into account the allowed disk inclination \((0.05 \leq 0.80^\prime)\), \(M_{\odot}\) varies in the range of \(2.5 \times 10^6 M_{\odot}\). \(2 \times 10^6 M_{\odot}\). The observed rotation curves are not well matched by the model but the good agreement with the accurate I-band images (\(M_{\odot} = 2.3 \times 10^6 M_{\odot}\)) and especially this is at odds with the BH inclination within the inner \(0.05-0.08^\prime\) from the nucleus \(\langle P \leq 0.50\rangle\) to the nuclear region. The comparison of the BH mass estimates in early type spirals presented in this paper with others from the literature. Although the sample is still small (6 detections and 2 upper limits). Spiral galaxies seem to follow the relation of BH-inclination scaling relations in early type galaxies (Fig. 5). The comparison between the BH mass estimates in early type spirals with others from the literature. Although the sample is still small (6 detections and 2 upper limits). Spiral galaxies seem to follow the relation of BH-inclination scaling relations in early type galaxies (Fig. 5). The comparison between the BH mass estimates in early type spirals with others from the literature. Although the sample is still small (6 detections and 2 upper limits). Spiral galaxies seem to follow the relation of BH-inclination scaling relations in early type galaxies (Fig. 5).