Black Holes from Stars to Galaxies – Across the Range of Masses
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The central 80×200 pc of M83: how many black holes and how massive are they?

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Abstract. The central $\approx 80 \times 200$ pc of the barred spiral galaxy M83 (NGC 5236) has been observed with the GEMINI-S+CIRPASS configuration which produced 490 spectra with a spectral resolving power of 3200, centered at 1.3 microns, oriented NW-SE. We determine the kinematics of this region with $0.36''$ sampling and sub-arcsec resolution. Disk-like motions have been detected in Paβ at parsec scales around: a) the optical nucleus, b) the center of the external K-band isophotes coincident with that of the CO velocity map both also tracing the center of the bulge, and c) a hidden condensation located at (R,θ)=(158pc, 301°). The present resolution allows to detect other minor whirls, not discussed here. The disk around (a) has a radius of ~ 8 pc and the two around (b) and (c) can be traced approximately up to 50–60 pc from their kinematical centers.

The rotation curves have been fitted by Satoh like spheroids+disk indicating masses of $\approx 4 \times 10^6\ M_\odot$, 60–70 $\times\, 10^6 M_\odot$ and 30–40 $\times\, 10^6 M_\odot$ respectively. Limit to the masses of central BHs can be set by supposing that the central unresolved line broadening inside each condensations is dominated by the BH as far as allowed by the central error bars. The BH+Satoh models were smoothed with a 9 pc Gaussian. The upper mass limit derived for the BH is for (a) $\sim 10^6/\sin(i) M_\odot$, and for (b) and (c) 0.2–1.0$\times 10^6/\sin(i) M_\odot$. Many questions arise from this interesting nucleus: are we witnessing a unique phenomenon or simply a barred galaxy with ongoing strong SF in our backyard? Does each one of the condensations host a BH indeed? or is there only one at the bulge center? Which is the fate of this complex scenario?

Keywords. Galaxies: nuclei – black hole physics

1. Introduction

It is generally accepted that galaxies host Super Massive Black Holes at their center, as one of the sessions of this symposium testify. The cannibalism of small neighbors by large galaxies is a phenomenon that also deserve increasing attention nowadays. Questions that naturally arise in these cases are if accreted satellites carry their own BHs, how massive they are and how much do they contribute to the large host galaxy central BH mass.

M 83 is a unique case for this type of studies, because of its proximity and the richness of phenomena occurring in their central 300 pc. Indeed, the condensation traditionally recognized as its nucleus (hereinafter, ON, for optical nucleus) is observable at optical wavelengths and is off-centered by $4''$ to the NE with respect to the center of the external K band isophotes of the bulge which can be fitted by a de Vaucouleurs' law in an annular region between $\approx 10''$ and $40''$ (Jensen *et al.* 1981, Gallais *et al.* 1991). Thatte, Tecza & Genzel (2000) demonstrated that the bulge center host an obscured condensation (kinematical center, KC). These authors claims that if KC and ON are virialized systems, they should have comparable masses $M_{KC} = M_{ON} \approx 13.2 \times 10^6\, M_\odot$ inside 5.4 pc in a cluster or a super massive core. CO interferometry (Sakamoto *et al.* 2004) shows

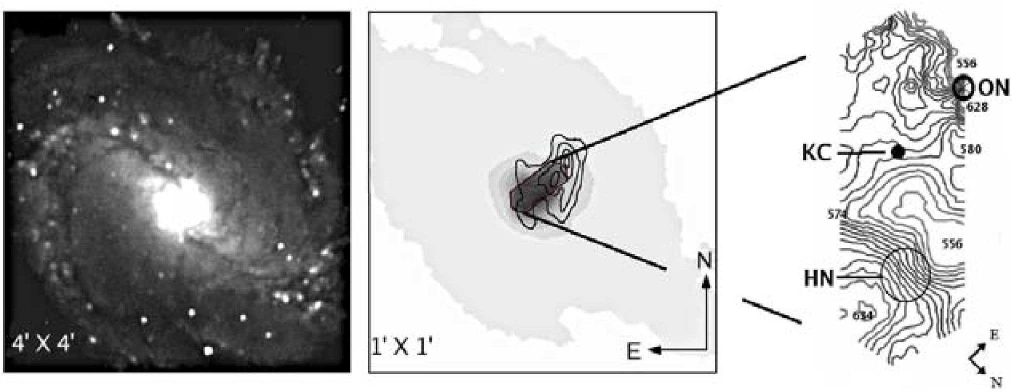

Figure 1. Image of M83 with zoomed central $1' \times 1'$ showing the position of CIRPASS array (ached area) superposed to the 10 cm continuum isophotes. The iso-velocities map is presented in the last panel. The positions of ON, KC and HN are detached as well as some iso-velocity levels. In Díaz *et al.* (2006) ON is also referred as visible nucleus, KC as bulge geometrical center, and HN as intruder and dark rotation center.

steep velocity gradients across the ON and a mass of $3 \times 10^8 M_\odot$ within a radius of 40 pc, nevertheless, the spatial resolution in CO observations is of the order of $3''$ and inhibits conclusions about the precise position of the rotation center (see Díaz *et al.* 2006). Elmegreen *et al.* (1997) determined for ON a photometric mass of $M_{ON} \approx 4 \times 10^6\, M_\odot$ (Hot Spot 1 in their table 4). More recently, Mast, Díaz & Agüero (2006) demonstrated the existence of a third condensation, also hidden at optical wavelengths, which coincides with the maximum of continuum emission at 6 cm and 10 cm of a giant cloud (Telesco 1988) $7''$ to the WSW of KC. Díaz *et al.* (2006) propose that HN is a small galaxy been cannibalized. We discuss here high resolution 3-D spectroscopy of the central $4.7'' \times 13''$ enclosing the three condensations and the implications in connection with the putative Black Holes at the center of M83.

2. Observations

We used the Cambridge IR Panoramic Survey Spectrograph (Parry *et al.* 2000, 2004) installed on the GEMINI South telescope in March 2003. These observations, performed in queue mode, were taken with an integral field unit (IFU) sampling of $0.36''$ (7.8 pc) in an elliptical array with size $4.7'' \times 13''$. The IFU was oriented at PA 120^o and centered slightly to the NW of the kinematical center, according to Mast *et al.* (2002). It was exposed during 45 minutes and covers an spectral range between 1.2–1.4μm, including Paβ 1.3μm and the [FeII] 1.26μm. The spectral resolution is approximately 3200. During the observations the peripheral wavefront sensor of GEMINI active optics was used to achieve a FWHM of approximately $0.5''$, therefore the focal plane was slightly sub-sampled by the configuration constrain.

The data were reduced using IRAF, ADHOC and SAO. Details about the reduction are presented by Díaz *et al.* (2006) and the general technique is thoroughly discussed by Díaz *et al.* (1999) and Mast *et al.* (2002).

3. 2-D kinematics of M 83 central region

In Figure 1 we show the Paβ iso-velocity contours on the 2-D radial velocity map. Three spider diagrams can be well differentiated on the complex 2-D radial velocity map.

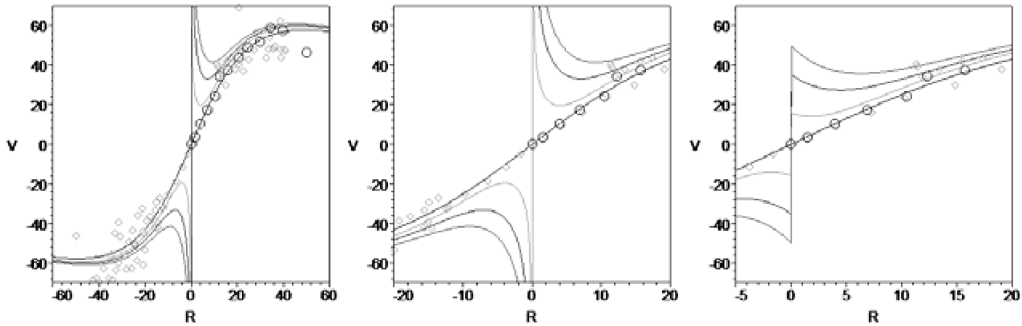

Figure 2. HN rotation curve. The squares are more than 50 velocity points obtained from the spider diagram. Circles are velocities mean values from receding and approaching side. Full line represent Satoh's best fit to the circles. The curves resulting from adding point like masses of 0.2×, 1× and 2×$10^6\,M_\odot$ to the Satoh's spheroid are also shown. The Satoh+Kepler velocity diagrams were filtered with a 9 pc Gaussian, to mimic the central velocity dispersion (bar length at r=0) which can then be compared to the observed one (table 1).

Table 1. Condensations and putative BHs properties

object	radius [pc]	v [km/s]	σ [km/s]	M_k [$10^6 M_\odot$]	M_{BH} [$10^6 M_\odot$]
ON	8 ± 1	46 ± 9	110 ± 10	3.7 ± 2	$\leqslant$1.0
KC	65 ± 5	68 ± 8	82 ± 10	66 ± 1.2	$0.2 - 1.0$
HN	45 ± 8	58 ± 11	96 ± 10	36 ± 1.2	$0.2 - 1.0$

One coincides with the optical nucleus (ON), a second condensation is coincident with the bulge center (KC), and a strongly absorbed third one (HN) has the largest local radial velocity gradient. A detailed description of the M83 central region astrometry can be found in Díaz *et al.* (2006).

The three condensations show well defined spider diagrams indicating that the P_β emitting gas is disk-like ordered (figure 1). KC shows an inclination of 68° ± 10° is The HN inclination is 50° ± 10°, Díaz *et al.* (2006). In figure 2 we present the rotation curve for this body which was fitted with a Satoh's spheroid to which three Keplerian masses were added, representing a putative BH. A 9 pc mask was applied to the cases of Satoh+Kepler rotation curve in order to reproduce the system spatial resolution. To decide which is the highest acceptable BH mass we use two criteria, namely, the velocities error bar and the observed central velocity dispersion. Observed kinematical data and deduced masses are presented in table 1. Reasonable BH upper mass limits are between 0.2 and $1.0 \times 10^6 M_\odot$ for KC and HN.

Based on the kinematical data we have run numerical simulations using GADGET2 Springel (2005), in order to study the dynamical evolution in the central region of M83. We considered the three condensations: KC, ON and HN, and followed the evolution of their stellar and gaseous components. KC, used as reference, was placed at the center of a large disk representing the inner part of M83 bulge ($2 \times 10^8\,M_\odot$). A total of 10^5 particles have been used and different orbits have been tested. The main result is that ON, KC and HN will merge, forming a single massive core in less than 50 Myr.

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4. Conclusions

The spatial resolution achieved with this observations allows to better constrain the masses of possible central very dense objects in the ON and KC (Thatte *et al.* 2000). The presence of a BH more massive than $10^6\,M_\odot$ within the condensations seems to be ruled-out. Our numerical simulations show that ON, KC and HN will merge forming a single massive core in less than 50 Myr. The existence of two distinct resonance circles, discussed in the literature (e.g. Elmegreen *et al.* 1997; Sakamoto *et al.* 2004) seems to be, from the point of view of the central region stability, totally irrelevant, since they are not able to preserve the region identity, as seen today.

The short dynamical timescales of the reported merger make of this phenomenon a unique one (probability less than 1% per galaxy). Since the Centaurus-Hydra group to which M83 belongs together with NGC 5128, NGC 5236 and others minor galaxies is so rich in activity, it is natural to rise the question on why should not have occurred a previous capture of this type by M83. It is important to detach from this point of view that object 28 in Maddox *et al.* (2006) list is a radiogalaxy projected on M83 disk which presents radio-lobes (objects 27 and 29 in the list) aligned with the galactic bulge at a projected distance between 1 and 2 kpc. Although the object has been characterized as a background galaxy with radio-lobes of type FII (Soria & Wu 2003), the curious alignment leads to think on the possibility of a kicked-off BH (Micic, Sirgudson & Abel 2005; also Madau's and Rees' talks at this Symposium) produced in a previous merger, similar to that occurring presently with the HN.

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