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# Supermassive black holes in the center of disk galaxies

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**Abstract.** We present the activity of the COFIN 2001-2003 Reseach Project 'Supermassive Black Holes in the Center of Disk Galaxies' co-finaced by the Italian Ministry for University and Scientific Reseach. The research team consists of 3 units working in Padova, Arcetri and Trieste. Aim of the project is to study the $M_\bullet - \sigma$ relation. In particular we plan to derive the mass of the central supermassive black hole (SMBH herefter) for about 60 spiral galaxies ranging from Sa to Sc and including both quiescent and active objects. We are going to use our spectroscopic and photometric data at high spatial resolution obtained both from ground-based and Hubble Space Telescope observations to reveal the presence of SMBH's in the mass range between $10^6$ and $10^{10}$ $M_\odot$. With the new data we will expand the study of the correlations between SMBH's and the characteristics of the host galaxies over a larger range of masses and morphological types and to shed light on the link between formation of quasar and of their host galaxies.

**Key words.** galaxies: elliptical, lenticular and cD – galaxies: spiral – galaxies: active – galaxies: kinematics and dynamics – galaxies: nuclei – galaxies: structure

## 1. Introduction

It is commonly accepted that almost every galaxy should host in its center a supermassive black hole (SMBH hereafter). SMBH's may have played a major role in galaxy evolution as recently the found correlation between the SMBH mass, $M_\bullet$, and the spheroid stellar velocity dispersion, $\sigma$ seems to witness. However it should be kept in mind that the current demography of SMBH's suffers of important biases, related to the limited sampling over the different basic properties of their host galaxies. In particular it is evident that the number of SMBH mass estimates in quiescent and active spiral galaxies is strongly underrepresented.

Therefore we propose to derive the mass of the central SMBH for about 60 spiral galaxies ranging from Sa to Sc and including both quiescent and active objects. We

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are going to use our spectroscopic and photometric data at high spatial resolution obtained both from ground-based and Hubble Space Telescope (HST hereafter) observations to reveal the presence of SMBH's in the mass range between $10^6$ and $10^{10}$ $M_\odot$.

The new data will allow us to expand the study of the correlations between SMBH and the characteristics of the host galaxies over a larger range of masses and morphological types and to shed light on the link between formation of quasar and of their host galaxies. The comparison between the local SMBH mass function and that derived from the AGN luminosity function will enable us to significantly constrain the physical processes which governs the evolution of quasar (e.g. the characteristic time of the quasar activity and the radiative efficiency).

In the following sections we give an overview of the Research Units and of their activities. The COFIN Principal Investigator is F. Bertola.

## 2. SMBH's in normal and active disk galaxies

Padova Research Unit
Local Coordinator: F. Bertola
Unit Members: C. S. Boschetti, S. Ciroi, L. Coccato, E. M. Corsini, M. D'Onofrio, L. Morelli, A. Pizzella, P. Rafanelli, C. Scarlata

The HST observations have greatly contributed in mounting the evidence that SMBH's are nearly ubiquitous in galactic centers and thus that they represent an integral part of galaxies (for a review see Ho 1999). Most of them should now constitute the relics of the intense quasar activity that occurred in the early phase of galaxy evolution and it is clear that they might have played an important role in the formation of galaxies (Sellwood & Moore 1999; Silk & Rees 1998). As a signature of this statement, correlations between central SMBH mass and host galaxy global properties are expected. Recent analysis led to establish a rather well-defined relation (verified for about 30 normal galaxies and about 10 Seyfert 1 galaxies) between the mass of SMBH's hosted in the nuclei of galaxies and the central stellar velocity dispersion (Gebhardt at al. 2000; Ferrarese & Merritt 2000). This relationship is narrower than the previous one where the SMBH mass was plotted against the luminosity (or the mass) of the spheroid (Kormendy & Richstone 1995; Magorrian et al. 1998). In this framework we are going to investigate both normal (F. Bertola, L. Coccato, A. Pizzella, E. M. Corsini, C. Scarlata, L. Coccato, L. Morelli) and active nearby galaxies (P. Rafanelli, M. D'Onofrio, S. Ciroi, C. S. Boschetti) in order to derive:

1. accurate determination of the SMBH mass in normal disk galaxies;
2. determination of the masses of SMBH and bulge in nearby AGN ($z < 0.1$).

### 2.1. Normal galaxies

Our immediate objective is the determination of 3 new accurate SMBH masses in disk galaxies with HST as well as the ground-based search for new spiral galaxies candidate to host a SMBH for a further HST follow up.

During HST Cycle 10, 12 orbits were assigned to us to perform STIS spectroscopy of three galaxies, namely NGC 2179, NGC 4343 and NGC 4435 in order to derive the mass of their central SMBH's. An accurate SMBH mass determination is assured since we know from ground-based observations that these objects are among the few disk galaxies possessing a CNKD (Rubin, Kenney & Young 1997; Bertola et al. 1998). The ground-based selection of the target objects ensures we are not embarking ourselves in a 'fishing expedition'! The sample galaxies are interesting candidates because (1) they are characterized by central value of stellar velocity dispersion ($\sigma_c \simeq 150-160$ km s$^{-1}$) much lower than those of the galaxies so far studied with ionized gas dynamics and higher than the few galaxies studied by means of water masers. SMBH mass determinations in the proposed velocity dispersion range, will allow a better comparison between this method and the stellar kinematic method. In fact to date the two methods do not have nearly as much leverage as all the data put together; (2) they should position themselves in the upper end of the $M_\bullet - \sigma$ diagram derived for disk galaxies, thus allowing us to better define the slope of the relationship for disk galaxies as compared to the one for ellipticals; They belong to morphological types (SB0, Sa, Sb) which are underrepresented in the sample of galaxies so far studied; (3) they will fall in the high-accuracy sample (Merritt & Ferrarese 2001) since they will be based on ionized-gas dynamics. Only two spirals (Milky Way and NGC 4258) belong to this sample to date. The addition of the Sa NGC 2179 and the Sb NGC 4343, the two spiral galaxies of this proposal, will double the sample of highly-reliable SMBH masses determined in spirals.

The analysis of CNKD kinematics (in collaboration with M. Sarzi) promises to be a straightforward way to reconstruct the gravitational potential in galaxy centers and therefore to derive the SMBH mass, because nearly circular orbits can be assumed for the gas. However the regularity of the gas velocity field has to be tested empirically case by case, since in the nuclear gas is more susceptible to non-gravitational forces and may not be in equilibrium. Moreover the central parsec-scale gas disk could not be coplanar with the main galaxy disk (e.g. NGC 3227, in Shinnerer, Eckart & Tacconi 2000). In order (1) to test the regularity of the ionized-gas velocity field in the target galaxies, (2) to derive the gas surface-brightness distribution, and (3) to constrain the CNKD orientation we proposed to acquire STIS spectra with the slit in three parallel close positions across the galaxy nucleus and along the galaxy major axis.

The stellar potential will be obtained by first deriving the stellar luminosity density from both archival HST images (for NGC 4343 and NGC 4435 visual WFPC2 frames are already available, while they are already planned for NGC 2179) and STIS acquisition images, and then assuming a constant mass-to-light ratio. The description of the observed surface-brightness distribution in terms of sum of Gaussian functions (Monnet, Bacon & Emsellen 1992) ensures both the deconvolution from the blurring of the HST point-spread function and the deprojection into the luminosity density profile (Sarzi et al. 2002). Once the total potential $\Phi = \Phi_{star} + \Phi_\bullet$ of the stellar component ($\Phi_{star}$) and the putative SMBH ($\Phi_\bullet$) is specified, the gas projected velocity field is simply obtained by computing at each point the circular velocity and by projecting it onto the sky plane according to the derived CNKD inclination. The comparison between the model-predicted and observed gas velocity fields will be done by taking into account the gas surface-brightness distribution, the HST point-spread function and the sampling over the basic slit apertures $0.05'' \times 0.2''$. This technique have already been successfully applied to the target galaxies by Bertola et al. (1998), where due to the low spatial resolution of our ground-based observations only upper limits for the central SMBH masses could be derived. This is the case of NGC 2179.

We are going to continue our ground-based high-resolution spectroscopic survey of nearby disk galaxies (Funes et al. 2002) to be combined with HST imaging to estimate an upper limit to the mass of the SMBH's present in their centers. This ground-based survey is complementary to HST observations, in the sense that, depending on the SMBH masses and ionized-gas distribution in the nuclear region, it will either give reliable SMBH masses or useful candidates for STIS follow-up spectroscopic observations of the stellar kinematics. We therefore selected a sample of 40 disk galaxies with (1) ionized gas; (2) a morphological type between S0 and Sc; (3) an inclination between 45 and 75 degrees; (4) a distance <20 Mpc; (5) with $\sigma_c > 130$ km s$^{-1}$; and (6) available archive HST imaging. The central stellar velocity dispersion of the targets is large enough that the corresponding SMBH masses from the $M_\bullet - \sigma$ relation will fall within the detection limits of our modelling approach. The position-velocity diagram of the CNKD obtained from the observations will be modelled in order to measure the central SMBH mass, and the whole spectra information will constrain the range of the possible unresolved ionized gas distributions. The observations of the first 20 objects are already scheduled at TNG and NTT telescopes.

In case a CNKD won't be detected we will have interesting candidates for further HST/STIS observations of the stellar kinematics in order to distinguish between two, equally intriguing, possibilities:

– the SMBH mass is the one expected from the $M_\bullet - \sigma$ relation, but the CNKD is not present due to the particular distribution of the ionized gas. This will allow us to increasing the present statistics of galaxies with or without central ionized gas concentrations (Rubin, Kenney & Young 1997; Bertola et al. 1998; Funes et al. 2002) and therefore to investigate eventual correlations between the presence of a CNKD with other galactic properties, such as the morphological type and nuclear activity;
– the SMBH mass is below the value predicted by the $M_\bullet - \sigma$ relation, suggesting a more complex scenario for the correlation of the properties of bulges, ellipticals and SMBH's.

### *2.2. Active galaxies*

More data are necessary to improve the statistics of the relationships $M_\bullet - M_{\rm sph}$ and $M_\bullet - L_{\rm sph}$ for Seyfert 1 (S1 hereafter) and Narrow-Line Seyfert 1 (NLS1 hereafter) galaxies. This project will be addressed to give an answer to the following questions:

1. Which are the typical SMBH and bulge masses of NLS1's? Do their masses have a strong dispersion around a mean value or are clearly distinguishable and separated from the range of masses typical of S1 galaxies?
2. Is the relation between mass of the SMBH and mass of the bulge the same as for S1 galaxies?
3. Is the environment playing a role in the formation and evolution of both bulges and SMBH? Then we should expect either that the environment of NLS1's is richer of galaxies than the environment of S1's or that the percentage of merging is higher in NLS1's than in S1's.
4. Which is the age metallicity connection in the Seyfert class?

The strategy that we are going to follow for giving a decisive and final answer to these problems is based on the use of the most advanced observational techniques applied to a sample of about 40 S1's and about 20 NLS1's for which we have studied the soft-X ray variability (Pfefferkorn, Boller & Rafanelli 2001). 7 of the NLS1's belong to a soft-X flux selected sample, $5\,10^{-11} < F(0.1{-}2.4\,{\rm keV}) < 5\,10^{-10}$ erg cm$^{-2}$ sec$^{-1}$, for which we have XMM data available.

We plan to carry out:

1. medium-resolution integral-field spectroscopy of the central regions ($16 \times 16$ arcsec$^2$ with MPFS, $8 \times 8$ arcsec$^2$ with PMAS) of the NLS1's and S1's samples to determine SMBH masses through the analysis of the Balmer emission lines coming from the Broad Line Region and subsequent application of photoionization calculations;
2. medium-resolution integral-field and long-slit spectroscopy to study the kinematics of the bulge stars and determine the velocity dispersion;
3. broad-band optical photometry to determine effective radius and magnitude of the bulges through bulge/disk decomposition of the surface brightness profiles, and to give insights into the metallicities and stellar populations of NLS1 and S1 galaxies. This step will

give us the bulge masses, their luminosities, to compare with the recent results from Laor (2001), and their velocity dispersions to test the more strong relation $M_\bullet - \sigma$ from Ferrarese & Merritt (2000);
4. wide-field imaging ($30 \times 30$ arcmin$^2$) to have large fields around each object and better study their environment identifying all the possible companion candidates.
5. medium-resolution multi-object spectroscopic surveys of such candidates to investigate their physical connection ($\Delta V < 1000$ km s$^{-1}$) to the active galaxy.

The already available data are:

- XMM observations of 7 fields of NLS1's (as mentioned above);
- a large amount of medium resolution long-slit and integral field spectra of NLS1's and S1's;
- multiband images of NLS1's and S1's.

Data on S1's will be used for building the control sample, necessary for evaluating the results on structural and environmental properties of our NLS1 galaxies.

## 3. SMBH's at the center of local spiral galaxies

Firenze Research Unit
Local Coordinator: E. Corbelli
Unit Members: C. Giovanardi, L. Hunt, A. Marconi

It has long been suspected that the most luminous AGN's are powered by accretion of matter onto supermassive black holes (SMBH; e.g. Lynden-Bell 1969). This belief, combined with the observed evolution of the space-density of AGN's (e.g. Sołtan 1982) and the high incidence of low luminosity nuclear activity in nearby galaxies (Ho, Filippenko & Sargent 1997), implies that a significant fraction of luminous galaxies must host black holes of mass $10^6 - 10^{10}$ M$_\odot$.

It is now clear that a large fraction of hot spheroids (E-S0) contains a SMBH (e.g. Kormendy & Richstone 1995; Macchetto et al. 1997; Marconi et al. 2001a) with mass proportional to the mass (or luminosity) of the host spheroid ($M_\bullet/M_{\rm sph} \approx 0.001$, Merritt & Ferrarese 2001). Recently Ferrarese & Merritt (2000) and Gebhardt et al. (2000) have shown that a tighter correlation holds between the SMBH mass and the velocity dispersion of the bulge. Clearly, any correlation of black hole and spheroid properties would have important implications for theories of galaxy formation in general, and bulge formation in particular. However, to date, there are very few secure SMBH measurements or upper limits in spiral galaxies even though we know that AGN's are common in such systems. In total, there are $\sim 40$ SMBH detections and only $\sim 20\%$ of these are in galaxy types later than S0. Only 2 in Sbc's and later (the Milky Way, Genzel et al. 2000, and NGC 4258, Miyoshi et al. 1995). It is therefore important to directly establish how common are SMBH's in spiral galaxies and if they follow the same $M_\bullet/M_{\rm sph}$, $M_\bullet/\sigma$ correlations as elliptical galaxies.

This can be achieved only with a comprehensive survey for SMBH's that covers quiescent and active spiral galaxies of all Hubble types. Such a survey would pin down the mass function and space density of SMBH's, and their connection with host galaxy properties (e.g. bulge mass, disk mass etc).

A determination of the large scale dynamical mass of the galaxy is also necessary in order to constrain the dark matter density in the innermost regions, and for evaluating the total dynamical mass of galaxies which host SMBH's. There are in fact several ambiguities in the dark halo model of a galaxy (core radius, radial slope of mass density, etc.) which can be tackled only by examining in detail the distribution of the various mass components, stellar, gaseous and dark, from the smallest to the largest dynamical scale (e.g. Corbelli & Salucci 2000). Local Group Galaxies are unique tools for this since they are spatially well resolved and they are at a well known distance, which eliminates part of the visible mass uncertainties. HST data have been already used to study the central structure of the highly resolved Local Group galaxies M31, M32, M33 and to infer the mass of a central black hole. The differences in the stellar light and velocity distribution in these three galaxies give rise to different masses for the central black hole and are clear signs that these galaxies have undergone different histories (Lauer et al. 1998). We plan to complement these optical studies with observations of the gas infall patterns toward the center (from induced mergers or from the gaseous disk) in order to understand the processes which prevent or trigger the transport of the gas inward to possibly fuel a SMBH (Kormendy & McClure 1993). Puzzling is in fact the low luminosity of many SMBH's in today's galaxies. They may be lacking fuel, or accreting without radiating effectively (Narayan et al. 1998). One intriguing possibility is that the growth of the hole is fostered by its location inside a thin bar, and ceases when the bar itself is destroyed when the black hole mass exceeds $\sim 0.02\ M_{\rm bar}$ (Pfenniger & Norman 1990; Sellwood & Moore 1999).

In this framework we are going to determine:

1. the SMBH frequency and mass function in the local spiral population;
2. the connection between SMBH's and host galaxy properties from young blue spirals to dusty AGN's.

### 3.1. SMBH's frequency and mass function in the local spiral population

We are undertaking a comprehensive survey for SMBH's in spiral galaxies, both quiescent and active to determine the mass function and space density of SMBH's, and to verify if any correlations of the SMBH mass with bulge mass and velocity dispersion holds for spiral galaxies. In early-type galaxies there are still worrying issues about the dynamical configuration of nuclear gas (e.g. misalignment with the major axis, irregular structure etc). By contrast nuclear gas in relatively quiescent spirals is organized into well defined rotating disks whose kinematic properties can be used to search for the presence of SMBH's. We identified a volume limited sample ($V < 2000$ km s$^{-1}$) of 54 Sb, SBb, Sc, and SBc spiral galaxies from a ground-based study by Axon et al. (private communication) who obtained H$\alpha$ and [N II] rotation curves at seeing-limited resolution of $1''$ for 128 spiral galaxies from the RC3 catalogue. The selected spiral galaxies are known to have nuclear gas disks and span wide ranges in bulge mass and concentration. The low redshift cut-off was chosen to ensure a high spatial resolution on source in order to detect even low-mass SMBH's. The frequency of AGN's in our sample is typical of that found in other surveys of nearby spirals, with comparable numbers of weak nuclear radio sources and LINERS. For each of the 54 spiral galaxies, we have obtained medium resolution spectra with STIS mounted on the HST at resolution $R \sim 6000$ or 3000. The use of HST guarantees a spatial resolution of about $0.1''$ which corresponds to 10 pc on a galaxy at a distance of 20 Mpc. The acquisition of HST/STIS data for the whole sample will allow the extraction of rotation curves for all these galaxies. For the few cases for which the data have already been obtained and analyzed, the rotation curves show a steep nuclear rise to a long plateau and presents the characteristic unresolved S-shaped velocity structure expected for Keplerian rotation around a mass concentration (e.g. Marconi et al. 2001b; van der Marel & van den Bosch 1998). This dynamical signature is accompanied by an abrupt increase of the emission line brightness toward the center, indicative of the presence of a well defined morphological structure, very likely a rotating circumnuclear disk. Comparison with the stellar brightness profiles derived from the STIS acquisition images will yield stringent lower limits on the $M/L$ ratios which can be used to infer the presence of a supermassive black hole. The work which we also plan in the near future is that of calculate and fit to the data the predictions of thin disk models with circular rotation.

### 3.2. SMBH's and their connection with host galaxy properties: from young blue spirals to dusty AGN's

The data described in the previous section will for the first time establish securely the SMBH mass function and any relations between SMBH mass and either bulge mass or central cusp slope. In order to determine the bulge mass we plan to use $K-$band near infrared images of these galaxies and apply the bulge-disk decomposition method by Moriondo et al. (1998). The $K-$band light is much less sensitive than $B-$band light (the one which has been used in the literature so far to infer the bulge mass) to reddening and mass-to-light ratio variations thus allowing a more robust determination of the bulge mass (Hunt et al. 1999; Moriondo et al. 1999). Since there does not exist an homogeneous set of $K-$band images for these galaxies we plan to apply for time at the ESO NTT telescope and at the Italian TNG telescope which can provide instruments with large field of view ($\sim 5 \times 5$ arcmin$^2$). Similarly it does not exist in the literature any measurement of the bulge stellar velocity dispersion in these galaxies, we are also applying for time at the 3.6-m ESO telescope, TNG, WHT and AAT (through our English collaborators). If the relation between SMBH mass and the bulge mass emerges we would also seek correlations between residuals from the mean relation and other galaxy properties such as bulge/disk ratio, bulge mass, disk mass etc. We are using archival HST (WFPC2 and NICMOS) and ground based (opt and near–IR) images of normal and active spiral galaxies to obtain bulge-disk 2D decompositions and isophotal signatures of bars/lenses which will be correlated with the presence of a SMBH.

As a by-product this investigation will provide a substantial, homogeneous and high-quality data base of galactic structural parameters. These will be used, in conjunction with evolutionary models to determine age and metallicity of bulges and disks and their dependence on morphology and environment. For the Local Group galaxies, M31 and M33, we are planning to complement the already published HST study of the nuclear region and black hole properties with a detailed study of the kinematic of the ionized, neutral, and molecular gas. The substantial difference in the estimated masses of central black holes for these galaxies ($M_\bullet = 3 \cdot 10^7$ $M_\odot$ in M31; $M_\bullet < 2 \cdot 10^4$ $M_\odot$ in M33) implies that these galaxies will be good candidates for understanding which are the conditions which favor the accretion of matter toward the center or if they represent an evolutionary sequence. These nearby galaxies are unique tools because they can be observed with the greatest spatial resolution and the nuclear region can be easily disentangled from the disk. For M33 a large H I survey made possible to determine the velocity field and the disk dynamic on a large scale (Corbelli 2000) and during this year the new 21-cm VLA survey will be available (Thilker et al. private communication) for studying the clouds gas motion in the inner region. We are planning to complement these 21-cm studies with molecular gas observation because the molecular component appears to dominate near the center. A first diffuse CO ($J = 1 - 0$) line emission map is already in progress at FCRAO, and it will be a great tracer of the innermost disk kinematic and dark halo (Corbelli, Heyer & Schneider, in preparation) and of possible gas fueling mechanisms. Follow up observations of the most relevant features will be done with higher spatial resolution. The beautiful spiral pattern of M33 is not so evident in M31 which instead shows a double-peaked nucleus dominated dynamically by a much more massive object (Lauer et al. 1998). Recent CO observations of this galaxy show that there are not strong concentrations of molecular gas in the center (Guelin et al. 2000; Heyer et al. 2000) but the gas is kinematically perturbed.

M31 can surely represent a much more evolved state than M33 and perhaps underwent several dynamical encounters. To test this hypothesis further we are planning WRST observations to map the entire galaxy and its periphery at 21-cm with high sensitivity (in collaboration with R. Braun and R. Walterbos). This will allow us to examine in detail the dark matter distribution and the detailed structure of the gas which is a good tracer of possible past merger events. For AGN's we have recently shown how it is possible to obtain secure SMBH measurements from the ground using an 8-m class telescope and a new generation infrared instrument. The well known radio galaxy Centaurus A is crossed by a prominent dust lane which strongly obscures the nuclear region (in the optical, $A_V > 7$ mag). Such dust extinction has not allowed any optical study of Centaurus A in the past but, using ISAAC at the VLT with excellent seeing conditions ($\sim 0.5''$) we were able to obtain a spatially resolved rotation curve which indicated the presence of a $\sim 2 \cdot 10^8$ $M_\odot$ black hole (Marconi et al. 2001a). Prompted by this success we will use observations at the VLT to study the SMBH masses in nearby obscured active galactic nuclei (Seyfert 1 and Seyfert 2 galaxies) which will allow a comparison of the SMBH mass with the AGN activity.

## 4. SMBH's and spirals: comparison with different cosmological theories and with ellipticals

Trieste Research Unit
Local Coordinator: P. Salucci
Unit Members: L. Danese

Recently, central SMBH's have gained a role of a fundamental component of galaxies and a tracer of their evolution. Since the study of nuclear SMBH's by Magorrian et al. (1998) the existence of massive compact objects at the centers of galaxies is not in doubt, though the value of their masses is somewhat uncertain due to a number of biases and complicated by some discrepant data. However, it is evident a connection between the mass and the evolutionary properties of the central compact supermassive object and the structural properties of the host galaxy. In ellipticals the situation is rather clear: the dynamics of the innermost regions usually reveal a central compact object (MDO), so that it is claimed that all galaxies contain a central supermassive black hole with a SMBH-to-spheroid mass ratio of $10^{-2} - 10^{-3}$ $M_\odot$. These SMBH masses result large enough to match those associated with the QSO phenomenon. The highest bolometric luminosities of quasars ($L_{\rm bol} < 4 \cdot 10^{48}$ erg $s^{-1}$), under the assumption that they radiate at the Eddington limit, imply underlying SMBH masses of $3 \cdot 10^{10}$ $M_\odot$, which are comparable with those of the largest MDO's detected in ellipticals (Magorrian et al. 1998), while the lowest QSO bolometric luminosities ($L_{\rm bol} = 10^{46}$ erg $s^{-1}$) still imply considerable SMBH masses, of the order of $2 \cdot 10^8$ $M_\odot$, detected in some bulges of Sa. More in general the mass function of SMBH remnants matches that of the amount of accreted material which is at the origin of the quasar phenomenon (Salucci et al. 1999). The SMBH masses in ellipticals and Sa show two fundamental correlations. First, a correlation with the luminosity of the galaxy spheroid. It is found (Ferrarese 2000) $M_\bullet = 0.9 \cdot 10^8$ $M_\odot$ $(L_{B,\rm sph}/10^{10} L_{B,\odot})^{1.1}$ that, since $M/L \sim L^{0.2}$, implies that the SMBH mass results roughly proportional to bulge mass. Second, a correlation between SMBH mass and the projected luminosity-weighted velocity dispersion, $\sigma$ within the effective radius $r_e$, which is a straightforward observational quantity but a very complex physical one $M_\bullet = 1.2 \cdot 10^8$ $M_\odot$ $(\sigma/200 \text{ km s}^{-1})^k$ with $k$ ranging between 3.75 and 4.5. The first relationship is rather a strong trend:

its scatter is large, its r.m.s. is about 0.5 dex and the range of SMBH masses at a fixed magnitude well exceeds a factor 10. It is then an open question whether it is real or only a biased envelope of a distribution that extends to smaller, undetected $M_\bullet$. In sharp contrast, the scatter of the second relationship, $M_\bullet$ vs. $\sigma$ is much smaller, and there are no discrepant galaxies (Ferrarese & Merritt 2000). One could argue that the $M_\bullet - \sigma$ correlation is more fundamental than the $M_\bullet - M_{\rm sph}$ (Kormendy 2001), in spite of being only a mysterious link between dark halo, stellar and SMBH mass. Further, it seems to have a scatter even smaller than that we expect on the basis of measurement and modelling errors. Salucci et al. (2000) have studied the innermost kinematics of spirals to investigate whether they host the massive black hole remnants that once powered the QSO phenomenon. Hundreds rotation curves of early and late-type spirals have been used to find that: (1) in late-type spirals, the central massive dark objects (MDO's) are about 10-100 times smaller than the extrapolation of the relationship $M_\bullet$ vs. $M_{\rm sph}$ holding for ellipticals; (2) in early-type spirals, the central bodies are likely in the same mass range of the elliptical MDO's. As a consequence the emerging picture is (1) the contribution to the QSO population by the SMBH remnants hosted in spirals is negligible. Spirals may host only the low energy part of the QSO/AGN phenomenon, spheroids the complementary high energy part; (2) the MDO mass vs. bulge mass relationship is qualitatively steeper in spirals than in ellipticals, however its very existence has to be checked yet. Up to date, few measurements supplemented by a number of upper limits indicate that in spirals SMBH masses do not correlate with luminosity in the same way as spheroids do (Ho 1999; Salucci 2000). The most recent analysis of observations suggests to resort to a nonlinear relation between the black hole mass and the bulge mass to account for the low-SMBH mass of active spirals $M_\bullet \sim M_{\rm sph}^{1.53\pm0.14}$ (Virani et al. 2000). This result raises the questions of a variable SMBH/B ratio among galaxies of different luminosity and Hubble type (Laor 2001).

Therefore, summarizing the mass function of supermassive SMBH's in galaxies is known only for bright ellipticals and the most powerful active galaxies while it is practically unknown for normal spirals and low activity SBMH's; the SMBH-galaxy coupling show itself but it is poorly understood, and finally, the SMBH growth by accretion and the process of galaxy formation are closely linked.

Theoretical work on the structure of galaxies and crucial data available from planned observational campaigns that include HST and telescopes of the 8-m class, will be used to investigate the evolutive scenario of the SMBH's at the center of spirals. The main tasks assigned to the Trieste research unit are:

1. To derive the theoretical cosmology-dependent relation

$$\sigma = f(M_{\rm sph}, r_e, M_{\rm halo})$$

for spirals and ellipticals in order to put in a physical context the phenomenological correlations between central SMBH's and properties of host galaxies. This is far from being trivial in that it requires accurate modelling of the properties of massive dark halos, including their density distribution and the rotational state of the stellar spheroids. In our group we have a large experience in this modelling.

2. By analizing spectroscopic and photometric data obtained by the collaboration, our research unit will determine the chemical properties and the age of the stars in the circumnuclear regions of the observed galaxies. The analysis will be done by using sophisticated models of the chemical and spectrophotometric evolution of galaxies already worked out by our research group. The results, coupled with with the observed structural and kinematical properties of these regions (bars, bulges and pseudobulges),

will be used to fully characterize the circumnuclear regions. The aim is to cast light on the relationships between the SMBH's and host galaxies of our sample.

3. Adding the results obtained by our collaboration to the data from literature, we will derive the Local Mass Function of SMBH's. Then we will compare it to the Mass Function derived from the evolving Luminosity Function of QSO/AGN. This result, coupled with the constraints coming from the clustering of QSO/AGN, will allow to determine very basic parameters like typical QSO duty cycle, $t_{\rm QSO}$, and the radiative efficiency of the accretion. Our group has large experience in this context, having obtained the first determination of the SMBH Local Mass Function.
4. We propose to make a comparative study of the $M_\bullet - \sigma$ and $M_\bullet - M_{\rm sph}$ relationships in elliptical and late type spirals, including non-linearity and scatter. We will try to interpret the possible differences in the terms the properties of the central regions (see point 2). In particular we will try to answer to vary basic questions. Why the SMBH masses in late spirals seem to be smaller than those in ellipticals having the same bulge mass? Is there a dependence of the SMBH mass on the degree of concentration of the stellar spheroid? Is the bulge mass the only driver for the SMBH growth ? How to explain the existence of AGN's in almost pure disks galaxies? Was there in every galaxy a 'dark compact seed' but spheroids rather than disks had enough material to rapidly feed the monster to grow and shine as a quasar?

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