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SIGNATURES OF MASS ACCRETION ONTO AGN FROM SUB-PARSEC TO KILOPARSEC SCALES

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RESUMEN

Se discuten los vestigios observacionales de los procesos de alimentación en Núcleos Galácticos Activos (AGN), desde el disco de acreción no resuelto hasta escalas de kiloparsecs. La geometría de discos de acreción comienza a ser accesible mediante las líneas de emisión con doble pico que aparentemente se originan dentro de varios miles de radios gravitacionales del agujero negro nuclear supermasivo (SMBH). El flujo de acreción en estos "picos dobles" (que poseen espectros de LINERS) y en otros LINERs es radiativamente ineficiente, lo cual sugiere que ésta es la forma dominante de acreción de masa hacia SMBHs nucleares en el Universo cercano. Cada vez son más numerosas las evidencias de la presencia de estrellas jóvenes que rodean al disco de acreción. Se han encontrado vestigios espectroscópicos de explosiones recientes de formación estelar en escalas desde parsecs hasta kiloparsecs alrededor del núcleo. A escalas similares, la morfología de galaxias anfitrionas de AGN revela por lo general un exceso de gas y polvo (en comparación con galaxias no activas), que delinean las espirales nucleares que podrían ser los canales de alimentación de SMBH nucleares. Pero hasta ahora existe sólo un caso (NGC 1097) para el cual la cinemática reciente de dos dimensiones revela movimientos de corrientes hacia el núcleo. Se necesitan nuevas observaciones con unidades de campo integral (IFU) de AGNs en altas resoluciones espaciales (mejores que 10 pc) para poder confirmar si este escenario es aplicable también a otros AGNs.

ABSTRACT

I discuss observational signatures of feeding processes in Active Galactic Nuclei (AGN), from the unresolved accretion disk up to kiloparsec scales. The geometry of accretion disks is beginning to be accessible via the double-peaked emission-lines, which seem to be originated within a few thousand of gravitational radii of the nuclear supermassive black hole (SMBH). The accretion flow in these "double-peakers" (which have LINER spectra) and other LINERs is radiatively inefficient (RIAF), suggesting that this is the dominant form of mass accretion towards nuclear SMBH's in the near Universe. Surrounding the accretion disk, there has been mounting evidence of the presence of young stars. Spectroscopic signatures of recent bursts of star formation have been found from parsec to kiloparparsec scales around the nucleus. In similar scales, the morphology of AGN host galaxies usually reveals an excess of gas and dust (relative to non-active galaxies) delineating nuclear spirals which could be the feeding channels to the nuclear SMBH. But there is only one case so far (NGC 1097) for which recent two-dimensional kinematics reveal streaming motions towards the nucleus. New observations with Integral Field Units (IFU) of AGN at high spatial resolutions (better than $\sim 10\,\mathrm{pc}$) are necessary in order to confirm if this scenario applies also to other AGN's.

Key Words: **GALAXIES: ACTIVE — GALAXIES: NUCLEI — BLACK HOLE PHYSICS — GALAXIES: STELLAR CONTENT**

1. INTRODUCTION

Over the last decade or so, a fundamental change has occurred in our view of nuclear activity in galaxies: while in the past the active galaxies where considered the ones which had a nuclear SMBH, now we believe that most galaxies which posess a bulge, also have a SMBH in its nucleus and nuclear activity is only a phase in the life of a galaxy in which the SMBH is being fed. In addition, we have learned that the evolution of the galaxy is closely tied to the evolution of the SMBH, as revealed by the proportionality between the SMBH mass and that of the bulges within which they reside (Magorrian et al. 1998; Ferrarese & Merrit 2000; Tremaine 2002).

The main problem of AGN research now is to unveil the processes which trigger and maintain the nuclear activity, allowing the feeding of the nuclear SMBH. Such processes occur in different scales: from the sub-parsec scales, via the accretion disk, through the parsec to hundred of parsec scales, where it is

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not so clear how the gas is transferred from galactic scales to the nuclear region, and up to the kiloparsec scales and more, where interactions between galaxies probably play a role. In this paper, I will focus on scales ranging from sub-parsec to kiloparsec. This paper is not meant to be a complete review, presenting a somewhat personal view of the topic, and including some recent results of my own research and that of my collaborators.

2. SUBPARSEC SCALE: THE ACCRETION DISK

The accretion disks around SMBH are not resolvable with presently available instrumentation. The first models of accretion disks were proposed by Shakura & Sunyaev (1973), being geometrically thin and optically thick, whose observational signatures are considered to be the big blue bump observed in the ultraviolet spectra of Quasars and Seyfert 1 galaxies. The big blue bump would correspond approximately to the peak of the blackbody energy distribution (or composition of black bodies) originating in the accretion disk (e.g. Sun & Malkan 1989).

A kinematic signature of the accretion disk, such as the double-peaked emission- lines, observed in cataclysmic variable stars, was first proposed by Chen, Halpern & Filippenko (1989), which showed that the double-peaked permitted lines of Arp102B were well reproduced by a model in which these lines were originated in the outskirts of an accretion disk. Since then, a number of other studies have collected such profiles: Eracleous & Halpern (1994), for a sample of more than 20 radio-galaxies, Storchi-Bergmann et al. (1993) for the LINER galaxy NGC1097, Bower et al.(1996) for M81, Shields et al.(2000) for NGC4203, among others. More recently, using spectra of the Sloan Digital Sky Survey (hereafter SDSS), Strateva et al. (2003) have found more than a hundred spectra with double-peaked emission lines.

We (Storchi-Bergmann et al. 2003) have followed the evolution of the double- peaked profiles in NGC 1097, and have derived a number of properties of the accretion disk, such as the inner and outer radii, mass of the black hole and evolution of the illumination of the disk. In a recent paper by Nemmen et al.(2006), we were able to model the spectral energy distribution (SED) of NGC 1097, having concluded that the inner accretion flow is radiatively inneficient (RIAF, for radiatively inneficient accretion flow, e.g. Narayan et al. 2000), which is geommetricaly thick and optically thin, and does not produce a big blue bump. This RIAF accretion seems to be the preferred mode of accretion of LINERs (e.g. Ptak et al. 2004). As LINERs are the most common type of activity in galaxies, it can be concluded that RIAF's are the most common type of accretion flow in the near Universe, although there is still some controversy about the contribution of jets in the reproduction of the SED's (e.g. Yuan et al. 2002).

3. SCALES OF TENS TO HUNDREDS OF PARSECS

3.1. *Spectral energy distributions*

We and others have studied the circumnuclear stellar population of active galaxies (e.g. Cid Fernandes et al. 1998, 2001, 2005; Storchi-Bergmann et al. 2000, 2001; Raimann et al. 2001, 2003, 2005; Gonzalez-Delgado et al. 2001, 2004). The main results of these studies can be summarized as follows: in about 40% of Seyfert 2 galaxies, we find recent star-formation (ages between 10^6 and 10^8 yrs), while this percentage drops to 10% for a control sample of non-active galaxies. For LINER's and radio-galaxies, a similar result is found, that is, a systematic larger contribution of younger stellar population in active when compared with non-active galaxies, only that the star-formation episodes are older, with dominant ages of $\sim 10^9$ yrs (intermediate age). An additional result, hinted by our studies, but evidenced by the much larger SDSS sample of galaxy spectra studied by Kauffmann et al. (2003) is that the most luminous Seyfert galaxies present the largest contribution of young stars to their spectra.

All the above results imply that circumnuclear star-formation is somehow connected to nuclear activity in galaxies, as long ago advocated by Terlevich and collaborators (e.g. Terlevich & Melnick 1985; Terlevich, Diaz & Terlevich 1990). The connection is probably provided by the transfer of gas from galactic scales to nuclear scales: in the way in, the gas may accumulate in the circumnuclear region and trigger star formation there. Extreme cases of young stars found very close to the nuclear SMBH are the galactic center, around which Eisenhauer et al. (2005) have found a number of young stars, and NGC1097 (Storchi-Bergmann et al. 2005) which has a 10^6 $M_\odot$ starburst within 9 pc from the nucleus.

3.2. *Morphology*

Back in 1976, Simkin, Su & Schwarz have argued that Seyfert hosts present a distinct morphology from that of galaxies with no activity, being more distorted, and having an excess of structures such as bars and rings. More recent works (e.g. Mulchaey & Regan 1996) did not find excess of bars in Seyferts;

others argue there is a small excess (Laine et al. 2002). Pogge & Martini (2002) and Martini et al. (2003) have analised HST images and color maps of active galaxies and concluded that Seyfert galaxies always present dust structures in the nuclear region, such as filaments and spirals, while many non-active galaxies do not present such structures. Xilouris & Papadakis (2002), also on the basis of HST images concluded that active galaxies of early Hubble types present more structure than a control sample of non-active galaxies.

We (Lopes, Storchi-Bergmann & Martini 2006) have recently selected a sample comprising all early-type active galaxies from the Palomar survey (Ho, Filippenko & Sargent 1995) which have optical images in the HST archive, as well as a control sample of non-active galaxies, and constructed "structure maps", a technique proposed by Martini & Pogge (1999) to enhance the contrast in the images. An example of structure maps of two pairs of active/non-active galaxies from our sample is illustrated in Fig. 1. Notice that the two active galaxies have dusty structures, while the control sample galaxies do not show such structures. This is the main result of our study, comprising a total sample of approximately 50 early-type galaxies: while most active galaxies present nuclear dusty filaments or spirals, these structures are rare in the control sample. Martini & Pogge (1999) have shown that nuclear spirals are not self-gravitating, and that they are likely to be shocks in nuclear gas disks. Maciejewski (2004) demonstrated that, if a central SMBH is present, nuclear disks of gas and dust can develop spiral shocks extending all the way to its vicinity and generate gas inflow compatible to the accretion rates observed in local AGN. Although the morphology of the dusty spirals does support the presence of gas inflow along dusty spirals, only two-dimensional kinematic measurements can provide a definitive answer. We have found such answer in at least one case: NGC1097, as described below.

4. STREAMING MOTIONS ALONG NUCLEAR SPIRALS IN NGC1097: THE LONG SOUGHT AGN FEEDING MECHANISM?

Prieto et al. (2005) have reported the presence of dark nuclear spirals surrounding the nucleus of NGC 1097 using near-IR images obtained with the ESO VLT telescope, arguing that these spirals could be the feeding channels to the AGN. We (Fathi et al. 2006) have provided kinematic evidence that this seems indeed to be the case. Using two-dimensional spectroscopy obtained with the Integral Field Unit

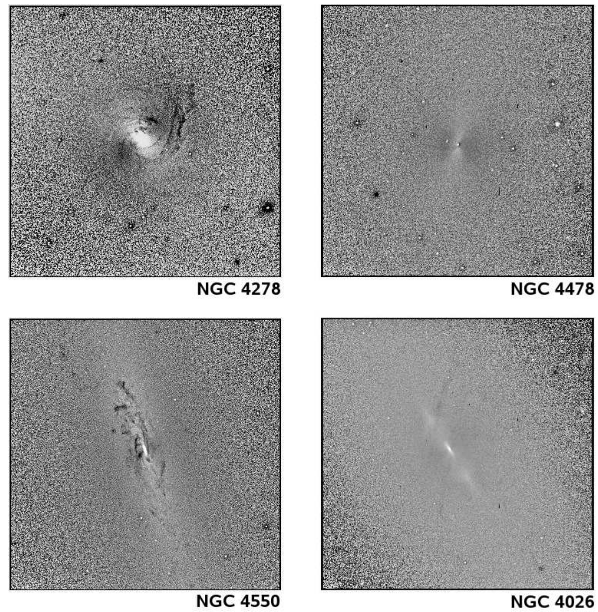

Fig. 1. Structure maps from HST F606W images for two active (left) and two non-active galaxies (right).

(IFU) of the GMOS instrument of the Gemini Observatory in the Hα spectral region, we were able to obtain the gas kinematics within 500 pc from the nucleus. The dominant velocity pattern is rotation, but, once a circular model is subtracted from the data, the residuals reveal streaming motions towards the nucleus, approximately delineating the spiral arms observed by Prieto et al. (2005), and also visible in processed optical HST images. The streaming velocities are observed all the way down to the nucleus within the spatial resolution of the observations, which correspond to $\sim$ 30 pc at the galaxy. These results are illustrated in Fig. 2.

5. CONCLUSIONS

We are beginning to collect unambiguous kinematic signatures of accretion disks around supermassive black holes in AGN, in the form of double-peaked emission-lines. The availability of data covering a large spectral range has also enabled the modeling of AGN spectral energy distributions, and are leading to the conclusion that the dominant form of mass accretion in the near-Universe is via RIAFs. Two-dimensional gas kinematics, now accessible via IFU observations through large telescopes seems also to have begun revealing accretion flows on larger scales, from tens of parsecs up to $\sim$ 1 kiloparsec. Although there is only one case published so far, IFU observations at spatial resolutions of $\sim$

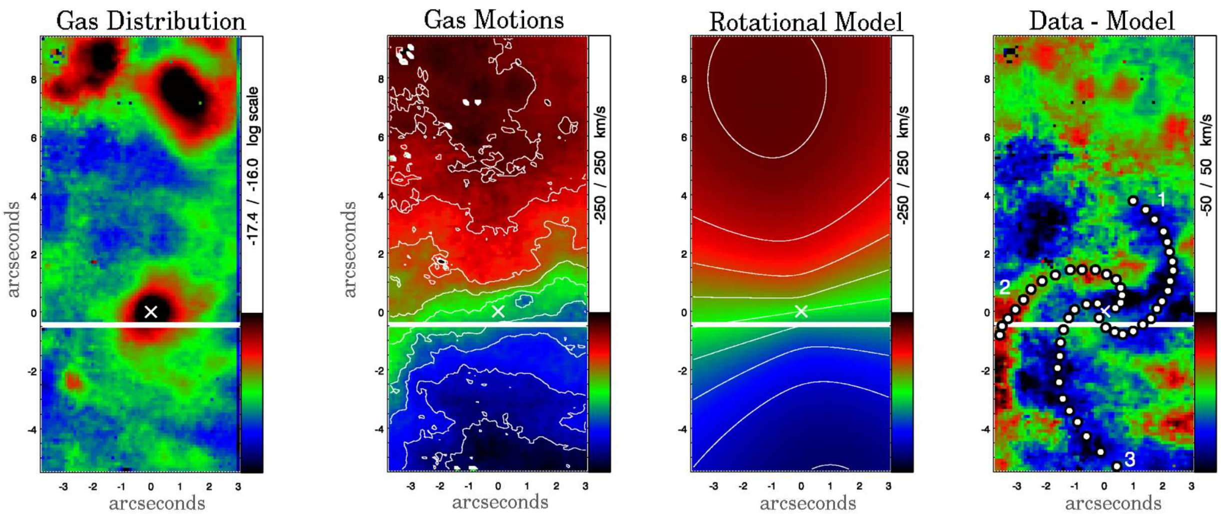

Fig. 2. GMOS-IFU results for NGC 1097. From left to right: [NII]6548,84 flux distribution, the velocity field derived from the peak wavelength of the [NII] emission-lines, best fit exponential disk velocity field model and residuals. Notice that the residuals delinate spiral arms observed in an HST image, traced by white dots in the figure. In the three rightmost panels, red color indicates redshift and blue color, blueshift. From Fathi et al. (2006).

10 pc of a large sample of nearby active galaxies will be able to probe the circumnuclear gas kinematics and finally reveal the nature of the feeding process of AGN's.

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