

Feeding the Monster

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Abstract. I present an overview of my recent work on the feeding of supermassive black holes (SMBH, *the monster*) in the nuclei of galaxies. This feeding is responsible to turn a "quiescent" galaxy into an active one, and proceeds at different spatial scales. At the smallest scales of a few light days in extent, there is the unresolved accretion disk, a disk of plasma where the mass spirals in until being accreted by the SMBH. At the largest scales, of tens of thousand of light years, interactions between galaxies may be the triggering mechanism to send gas towards the center of the galaxies. At intermediate scales, there is still some debate on how the transfer of matter to the nuclear region occurs, and the best candidates seem to be large scale bars, present in at least half of the spiral galaxies. In the inner thousand light years, it is difficult to see observational evidence of inflow of gas, as in most active galaxies, this region is dominated by gas outflows. Nevertheless, in galaxies with low activity, where the outflows are weak, and using new techniques, I have been able to observe inflows in these region, which proceed along nuclear spiral arms.

Keywords: black holes, nuclei of galaxies, interstellar medium, accretion disks, gas kinematics

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INTRODUCTION

Over the last decade we have learned, mainly from observations with the Hubble Space Telescope, that most – if not all – galaxies which have a stellar bulge, harbor a Supermassive Black Hole (hereafter SMBH) in their nuclei, with a mass proportional to that of the bulge (1,2,3). The difference between an active and a non-active galaxy in this scenario is the fact that, in the former, the SMBH is actively accreting mass, while in the non-active galaxies, the SMBH is "starving".

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 scales of light days, via the accretion disk, through the inner thousand light year, where it is not so clear how the gas is transferred from galactic scales to the nuclear region, and up to galactic scales, where interactions between galaxies probably play a role. In this paper, I will focus on some recent results of my own research and that of my collaborators regarding the feeding of the nuclear SMBH in these different scales.

ACCRETION DISKS

The accretion disks around SMBH are not resolvable with presently available instrumentation, as they have radii of only a few light days. The first models of accretion disks were proposed by Shakura & Sunyaev (4), being geometrically thin and optically thick, whose signature has been observed in the spectral energy distribution of active galaxies as a composition of black body curves with temperatures around 10,000K (5), as the disk has a gradient of temperatures increasing towards the SMBH. Although this signature is expected to come from the accretion disk, it does not constrain its geometry, and the emitter could have any shape, not necessarily a disk shape. In 1993, we (6) have made an important discovery, which did constrain the geometry of the emitting structure: we found the kinematic signature of the accretion disk in the nearby galaxy NGC 1097, in the form of a double-peaked emission-line, as illustrated in Figure 1.

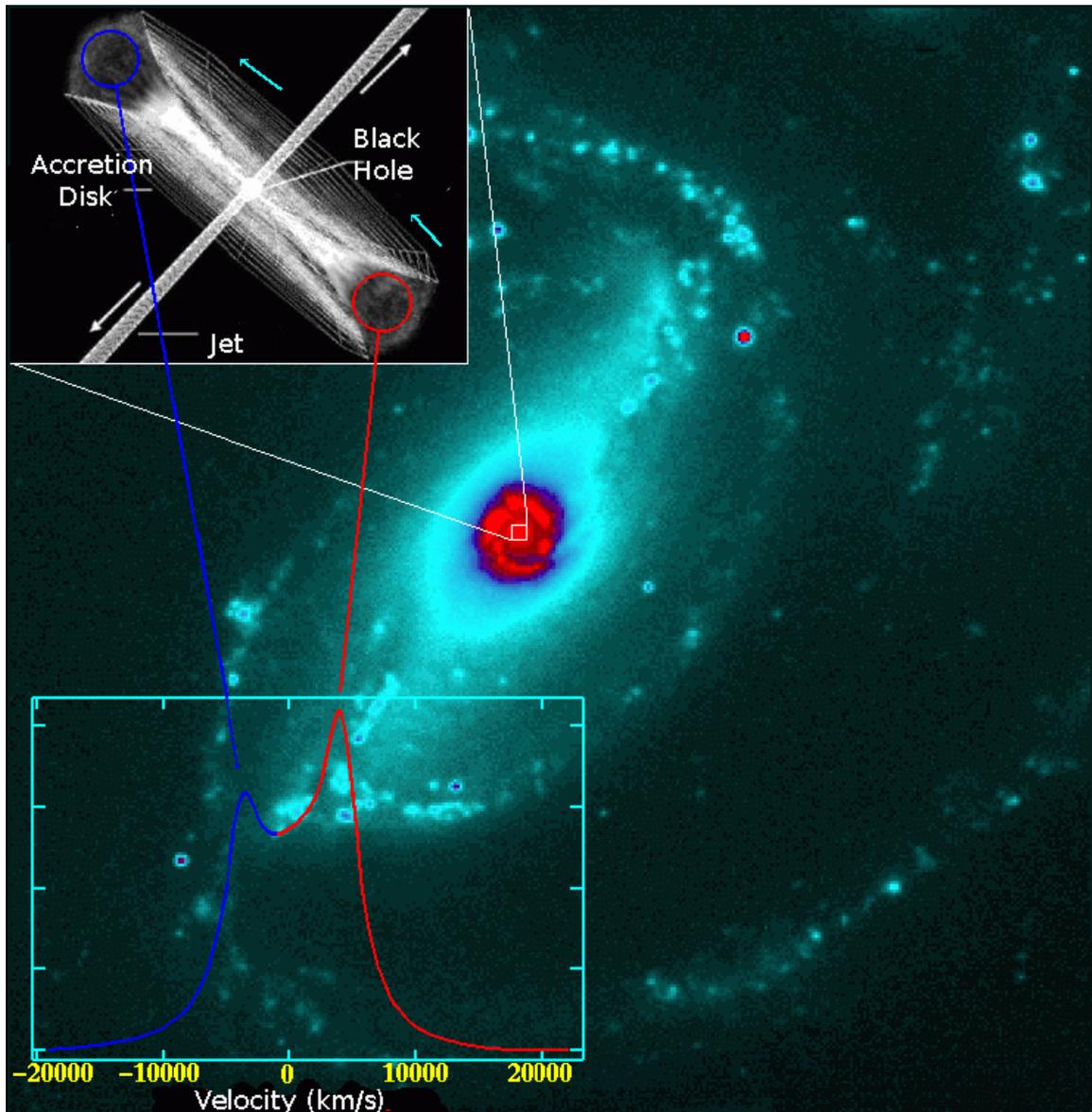


FIGURE 1. The galaxy NGC 1097, in which nucleus I discovered the kinematic signature of an accretion disk. The insert in the top left corner shows an artist's conception of the accretion disk, illustrating how it generates the double-peaked profile of an emission line, which is shown at the bottom. As the disk is rotating at velocities of thousands of kilometers per second, due to the Doppler effect, the approaching part of the disk produces a blueshifted emission while the receding part of the disk produces a redshifted emission. The result is a double-peaked profile both in wavelength and velocity coordinates. In subsequent papers (7,8,9) we have derived a number of properties of the accretion disk, such as the inner and outer radii, mass of the SMBH and have followed the evolution of the disk emission, finding that, over the years, it has faded, together with a spiral arm initially present in the disk. Later, with a PhD student, we (10) modelled the spectral energy distribution of the active nucleus of NGC 1097 and concluded that, in the inner part of the thin accretion disk, it flares up, and has the structure of an "ion torus".

EXTRAGALACTIC SCALES

Theoretical studies have proposed interactions among galaxies as efficient means to promote gas inflow to their

central regions to trigger nuclear activity. Nevertheless, observational results are controversial. Some works do find an association between interactions and the presence of nuclear activity (11), while others fail to find an excess of companions in samples of active galaxies when compared with control samples of non-active ones (12). In Storchi-Bergmann et al. (13), where we looked for signatures of interactions among a sample of 35 Seyfert galaxies, we found an excess of companions only for the sub-sample of active galaxies which showed an excess of young to intermediate age (10⁸ yrs) stars in the stellar population. The active galaxies dominated by older stellar populations did not show an excess of companions. We then proposed an evolutionary scenario, in which the interactions were the first step in sending gas inwards, which would then trigger both star-formation and the nuclear activity. Alternatively, the nuclear activity can be triggered after the starburst; the gas to feed the SMBH could come from the mass loss from the evolving stars. In any case, the starburst fades more rapidly than the nuclear activity. The result is that, during most of the active phase, clear signatures of interactions are mostly gone; they are only present shortly after the triggering of the starburst, which corresponds to a short fraction of the active phase. We have observed the signatures of the aging starbursts in the spectra of active galaxies (14,15), supporting a connection between the triggering of nuclear activity and the presence of circumnuclear starbursts.

THE INNER THOUSAND LIGHT YEARS

In order to look for accretion on the inner thousand of light years, we (16) have assembled a sample of active galaxies and a control sample of non-active galaxies matched according to the properties of the host galaxies. We have used galaxy images obtained with the Hubble Space Telescope and have constructed “structure maps” (a technique to enhance the contrast of the images). The results for the 34 early-type pairs of the sample are illustrated in

Figure 2: structures attributed to the presence of gas and dust are found in all active galaxies, but in only 27% of the non-active galaxies, which represents a strong correlation between the presence of dust structures and activity in galaxies. Our interpretation is that the dust is tracing the actual material in its way in to feed the SMBH.

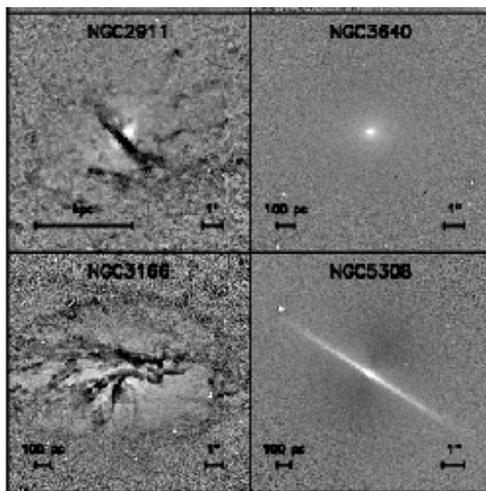


FIGURE 2. structure maps of the nuclear region of two active galaxies (left panels) as compared with those of two non-active galaxies (right panels). The structure map removes the smooth part of the image and enhances the contrast, revealing that the active galaxies have much more dark structures -- due to dust mixed with gas than non-active galaxies.

Two-dimensional Spectroscopy: a new technique

The kinematics of gas surrounding active nuclei is usually dominated by outflows which originate in the accretion disk. Jets emitted at the inner part of the disk push the gas surrounding the nuclei of the galaxies producing the observed outflows. Thus although we believe gas is reaching the center to feed the SMBH, inflows are seldom observed, because they become overwhelmed by the dominating outflows. Motivated by the strong correlation between activity and the presence of dusty nuclear spirals, suggesting that these spirals are channels to feed the SMBH, we have begun a project to measure the kinematics of these spirals using the integral field unit of the Gemini Multi-Object Spectrograph (GMOS IFU). The first results of this project were published in Fathi et al. (17)

for the galaxy NGC 1097, and in Storchi-Bergmann et al. (18), for the galaxy NGC 6951, in which we mapped the gas velocity fields within the inner thousand light years of the galaxies. Although the kinematics is dominated by rotation in a plane, the subtraction of a rotating disk model revealed streaming motions towards the nucleus along the spiral arms seen in HST images. Both NGC 1097 and NGC 6951 have low activity, and this is probably the reason why we can see the inflows: because the outflows are weak or absent. We are witnessing, for the first time within this region, the mass in its way in to feed the SMBH. Using the typical streaming velocities (50 km/s) and the observed geometry for the flow we have estimated the inflow rate in ionized gas, which gives values of approximately 10^{-3} solar masses per year and which coincide with the accretion rate necessary to power the active nuclei. Another study we just finished in the near-infrared, shows inflowing gas along a nuclear spiral arm in another active galaxy: NGC 4051 (19).

CONCLUSIONS

I have reviewed my work and of my collaborators on the observational signatures of feeding processes to the supermassive black hole in the nuclei of galaxies on three different scales: the accretion disk scale, the galactic scale and the inner thousand light years. Unambiguous kinematic signatures of accretion disks are the double-peaked emission-lines, whose monitoring allows the determination of physical parameters of the accretion disk and their evolution. On extragalactic scales, the favored mechanism to send gas inwards is interactions among galaxies, although the observational signatures are not very clear, probably due to a delay between the interaction and the triggering of nuclear activity. On the inner thousand light year, we have found a strong association between the presence of nuclear gaseous spirals and filaments and nuclear activity, which can only be understood if this gas is the actual fuel on its way in to feed the SMBH at the nucleus. This is confirmed by new results of observations of inflows along nuclear spirals using Integral Field Units on large telescopes.

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