The Central kpc of Starbursts and AGN
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Morphology of AGN in the central kiloparsec

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Abstract. Hubble Space Telescope observations of the central kiloparsec of AGN have revealed a wealth of structure, particularly nuclear bars and spirals, that are distinct from analogous features in the disks of spiral galaxies. WFPC2 and NICMOS images of a large sample of AGN observed at high spatial resolution make it possible to quantify the frequency and detailed properties of these structures. Nearly all AGN have nuclear spiral dust lanes in the central kiloparsec, while only a small minority contain nuclear bars. If these nuclear dust spirals trace shocks in the circumnuclear, gaseous disks, they may dissipate sufficient angular momentum to fuel the active nucleus.

1. Introduction

Nearly all galaxies appear to have central, supermassive black holes, yet only a small fraction host AGN. To fuel the mass accretion rates of $\sim 0.01 M_{\odot}$ yr^{-1} that powers nuclear activity in the Seyfert galaxies discussed here, there must be mechanisms that remove angular momentum from the host galaxy ISM and drive it within range of the central black hole. Galaxy interactions and bars can remove angular momentum and fuel nuclear activity; however, there remain many AGN that show no evidence of either a bar or a recent interaction.

We undertook a survey of Seyfert 2s from the CfA redshift survey with *HST* to look for evidence of additional mechanisms, such as nuclear bars (Shlosman et al. 1989; Pfenniger & Norman 1990), that could transport the host galaxy ISM from 100-parsec scales into the active nucleus. If fuel is continuously transported inwards, then evidence for gas flow traced by the dust morphology should be present. We have analyzed visible and near-infrared images from *HST* to map the stellar surface density and dust distribution in 24 Seyfert 2s and found a small percentage of them host nuclear bars, but nearly all have nuclear dust spirals.

2. Looking for nuclear bars

Nuclear bars are intrinsically more difficult to detect and characterize than large-scale bars as their semimajor axis lengths are on order one fifth as large. As the nearby AGN population is generally more distant than comparable non-active galaxies, the frequency of nuclear bars in AGN could not be examined with large samples before *HST* and NICMOS. To identify stellar nuclear bars we adopted

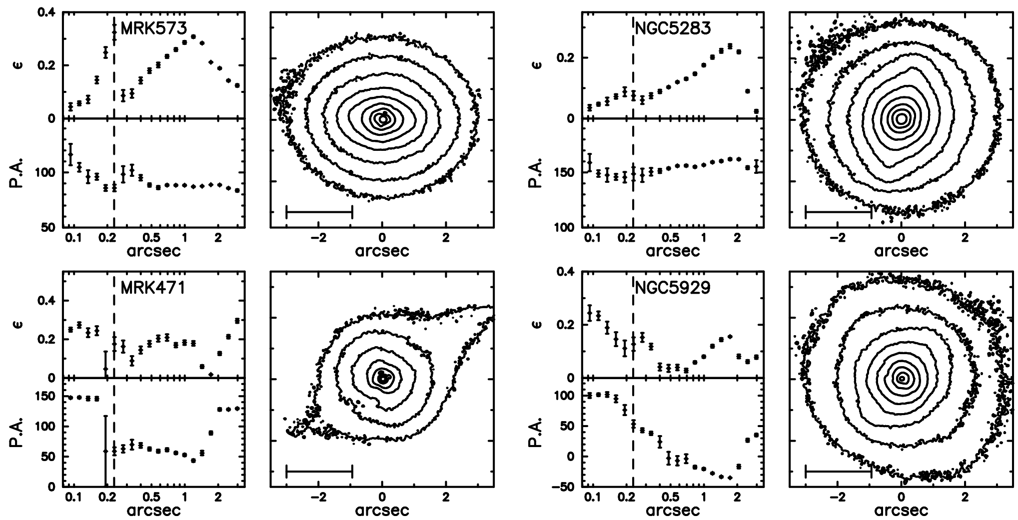

Figure 1. The four stellar nuclear bar candidates identified in an isophotal analysis of NICMOS images of the CfA Seyfert 2s. For each galaxy the ellipticity and position angle distribution as a function of semimajor axis length is shown in the left panels and the F160W surface brightness contours in the right panels. The bar in the lower left corner of the contour plots corresponds to 1 kpc.

the same selection criteria described by Mulchaey et al. (1997) and Knapen et al. (2000). These selection methods essentially look for increases in ellipticity at constant position angle, followed by a decrease in ellipticity at the end of the bar. Using these criteria we found evidence for stellar nuclear bars in the four galaxies shown in Figure 1: Mrk 573, NGC 5283, Mrk 471, and NGC 5929 (Martini et al. 2001). Our detection rate of $\sim 25\%$ (after accounting for selection effects) is similar to the detection rate reported by Erwin & Sparke (1999) and Márquez et al. (2000) for non-active galaxies. The apparently equal and low percentage of nuclear bars in active and non-active galaxies suggests that nuclear bars are not responsible for fueling most Seyfert galaxies.

The $V - H$ colormaps of Mrk 573, NGC 5283, and Mrk 471 shown in Figure 2 show evidence for straight dust lanes crossing their nuclei, while none of the AGN without nuclear bars have similar straight dust lanes. This suggests that the gas flow traced by the dust is associated with the nuclear bar. Mrk 573 and NGC 5283 are particularly striking cases as the morphology of the dust lanes mimics the dust pattern seen in large-scale bars (Quillen et al. 1995; Regan et al 1997). The dust lanes appear to trace the leading edges of the nuclear stellar bar and then cut across the nucleus as a straight dust lane along the nuclear bar minor axis.

3. Nuclear spirals as a potential fueling mechanism

While this study did not uncover a large percentage of nuclear bars in AGN, essentially all of these galaxies do have nuclear dust spirals on 100-parsec scales

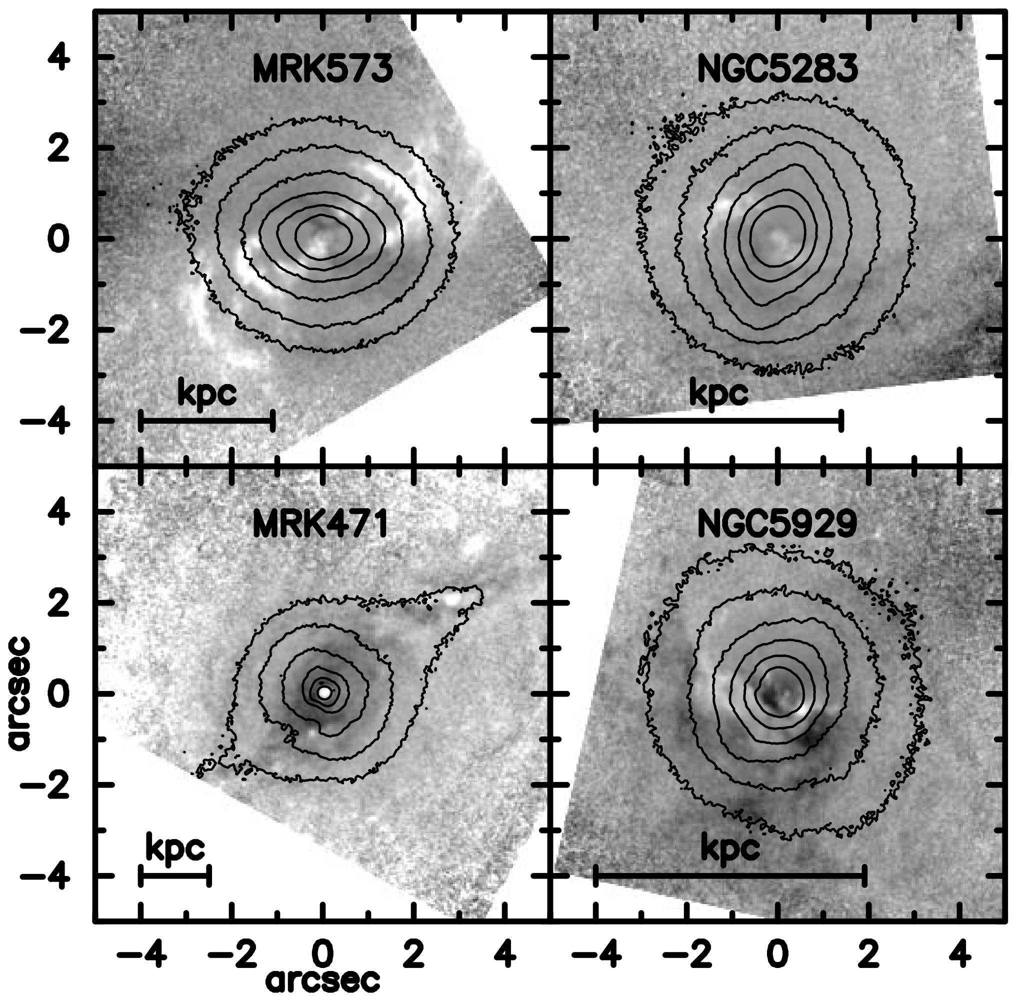

Figure 2. $V - H$ color maps of the four galaxies with nuclear bar candidates from Martini & Pogge (1999). The darker greyscale corresponds to greater reddening and traces the dust distribution. The contours are the same as in Figure 1.

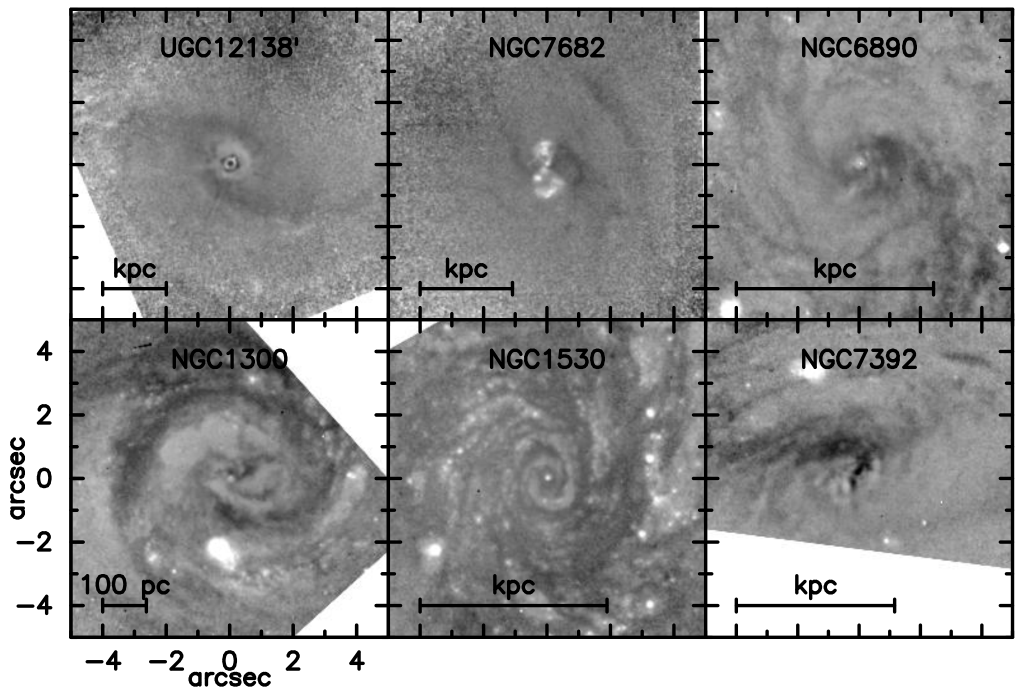

Figure 3. $V - H$ colormaps of galaxies with grand-design nuclear spiral structure.

(Martini & Pogge 1999). These nuclear dust spirals can be morphologically classified as primarily "flocculent" or "grand-design" in appearance, analogous to the spiral structure on kiloparsec scales in spiral galaxies. Examples of grand-design nuclear spirals in AGN are shown in Figure 3 (*top row*) and examples of flocculent spiral structure are shown in Figure 4 (*top row*).

Gaseous disks in the central kiloparsec of spiral galaxies are generally not self-gravitating and are in nearly solid-body rotation, in contrast to their main disks on kiloparsec scales, which are prone to gravitational instabilities and subject to considerable differential rotation. Instead of gravity, pressure dominates the gas response to perturbations in these central, gaseous disks and the presence of nuclear dust spirals on these scales are evidence for gas flow driven by hydrodynamic effects. Englmaier & Shlosman (2000) proposed that gas inflow from a large-scale bar can create grand-design nuclear spiral structure, such as that shown in Figure 3. All of the galaxies in our sample which show this grand-design spiral structure do have large-scale bars, which supports this model for the dust morphology. The flocculent spiral structure shown in Figure 4 may be due to the acoustic instabilities described by Elmegreen et al. (1998). In this model, small instabilities propagate as pressure-driven waves and are sheared by the small differential rotation in these disks to produce the flocculent structure (Montenegro et al. 1999). Both of these models for nuclear spiral structure propose that shocks create the density enhancements traced by these dust lanes. Shocks in these nearly ubiquitous spiral dust lanes is thus interesting in the context of AGN fueling as these shocks may dissipate sufficient angular momentum

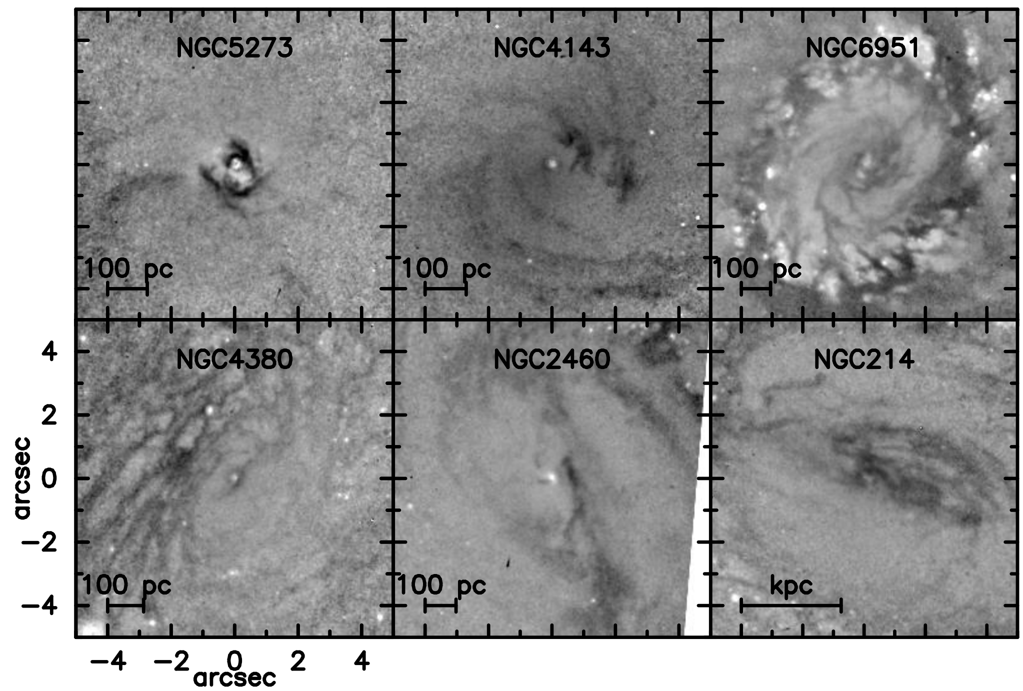

Figure 4. Same as Figure 3 for galaxies with flocculent nuclear spiral structure.

to fuel nuclear activity. Estimates of the rate of mass inflow in the context of theoretical models for both types of nuclear spiral structure are clearly needed to better assess its viability as a fueling mechanism for AGN.

Nuclear spiral structure has long been know to exist in nearby, non-active galaxies such as M100 and M101 (Sandage 1961), although the frequency of this structure has not been well characterized as it is rarely resolved in ground-based observations. Visible-wavelength *HST* images of the centers of spirals have uncovered more non-active galaxies with nuclear spiral structure, but it is not obviously present in all cases (Carollo et al. 1998). The near-ubiquity of nuclear dust spirals in AGN (see also Quillen et al 1999; Regan & Mulchaey 1999) and the possibility that shocks remove sufficient angular momentum to fuel the nuclear activity prompts a simple question: Are nuclear dust spirals present with equal frequency in non-active galaxies? If they are not, this would be strong evidence in favor of a causal connection between nuclear dust spirals and the fueling of AGN.

We are currently imaging a large sample of non-active galaxies with WFPC2 on *HST* that have previous NICMOS images in order measure the frequency of nuclear spiral structure in a well-matched control sample. While these observations are not yet complete, we have found non-active galaxies which show grand-design (Figure 3, *bottom row*) and flocculent (Figure 4, *bottom row*) nuclear dust spirals. A preliminary result of this survey is that nuclear spirals structure is fairly common in non-active galaxies, although we do not yet have an adequate sample size to properly characterize the relative frequency of these structures in active and non-active galaxies, or to look for trends with Hubble type and other galaxy properties.

4. Implications for AGN fueling

The main problem with nuclear spiral structure as a fueling mechanism for AGN is quite different from that of bars and interactions, namely it appears to be too common rather than too rare. These observations indicate that AGN and non-active galaxies have similar morphologies, whether nuclear spirals or nuclear bars, on 100-parsec scales. One simple interpretation is that the typical lifetime of low-luminosity AGN is less than the dynamical time on 100-parsec scales, which corresponds to a few times 10^7 years.

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