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A nuclear grand-design spiral within the normal disc spiral of NGC 5248

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ABSTRACT

We report the discovery of trailing grand-design nuclear spiral structure in the spiral galaxy NGC 5248. Two tightly-wound red spiral arms, with widths less than 1 arcsec ($\sim$ 75 pc), emanate at 1 arcsec outside the quiescent nucleus of the galaxy, and can be followed for 3 arcsec, appearing to end before the radius of the circumnuclear starburst "ring", which is at 5–6 arcsec or around 400 parsec. Combining our near-infrared Canada–France–Hawaii Telescope adaptive optics results with traditional near-infrared and optical imaging, we show that spiral structure is present in this galaxy at spatial scales covering two orders of magnitude, from a hundred parsecs to 15 kpc. Comparison with a *Hubble Space Telescope* ultraviolet image shows how the location of the circumnuclear star formation relates to the nuclear spiral structure. We briefly discuss possible mechanisms which could be responsible for the observed nuclear grand-design spiral structure.

Key words: galaxies: spiral – galaxies: individual: NGC 5248 – galaxies: starburst – galaxies: structure.

1 INTRODUCTION

Little is known about the structures that govern the dynamics of disk galaxies within the central few hundred parsecs. Colour index images, made by combining two broad-band optical or near-infrared (NIR) images, allow us to study the dust lane morphology in the nuclear region, which is important for constraining numerical models of gas dynamics in the circumnuclear region (see, e.g., Knapen et al. 1995a). Structures expected in the nuclear region include trailing or leading spiral structure or bars (e.g., in M100; Knapen et al. 1995b), and star forming (SF) regions (e.g., Elmegreen et al. 1997; Ryder & Knapen 1998).

Nuclear spiral structure has been observed recently in a number of galaxies. These cases include the discovery of small-scale flocculent dust spirals in the cores of NGC 278 (Phillips et al. 1996), NGC 2207 (Elmegreen et al. 1998) and others (Carollo, Stiavelli & Mack 1998). More chaotic dust lane structures have been seen in *Hubble Space Telescope (HST)* WFPC2 images of M51 (Grillmair et al. 1997), M81 (Devereux, Ford & Jacoby 1997) and M87 (Ford et al. 1994; Dopita et al. 1997). High resolution *HST* NICMOS and adaptive optics (AO) Canada–France–Hawaii Telescope (CFHT) NIR images have also revealed nuclear spirals (Regan & Mulchaey 1997, 1998; Rouan et al. 1998).

We report the first detection of nuclear "grand-design" spiral structure as seen in NIR AO images of NGC 5248, a galaxy classified as SXT4 by de Vaucouleurs et al. (1991; RC3). We compare our new data with UV, optical and NIR images that cover a large range of size scales. We use a distance of 15.4 Mpc to the galaxy ($v_{\rm sys}$ = 1153 km s^{-1}; RC3), which implies that 1 arcsec corresponds to 75 pc. NGC 5248 has a circumnuclear starburst "ring" (Pogge 1989; Maoz et al. 1996; Fig. 1), but its nucleus is quiescent, as evidenced spectroscopically (Storchi-Bergmann, Wilson & Baldwin 1996; Ho, Filippenko & Sargent 1997). The circumnuclear SF properties of NGC 5248 were recently studied by Elmegreen et al. (1997), and the dynamics of the main spiral structure were modelled by Patsis, Grosbøl & Hiotelis (1997).

2 OBSERVATIONS

The *J*, *H* and *K* band images were obtained in 1997 March at the CFHT using the combination of the AO system

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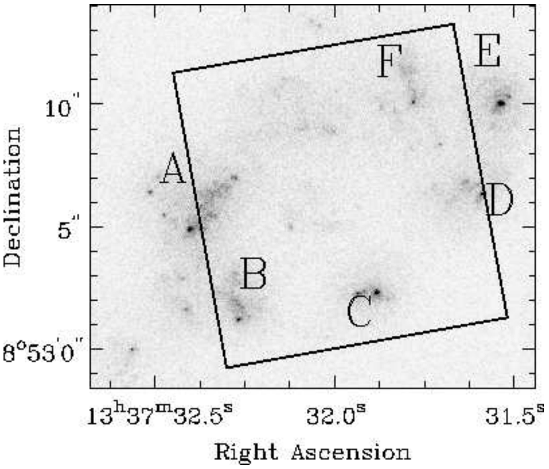

Figure 1. An *HST* Faint Object Camera F220W ultraviolet image of the starburst "ring" in NGC 5248. The coordinates are in J2000.0. Some of the SF sites are marked with letters A–F for comparison with the NIR images presented in Fig. 2. The area that is covered by the CFHT images presented in Figs. 2 (left) and 4 has been marked with a box.

PUEO (Rigaut et al. 1998a) and the Montréal NIR camera MONICA (Nadeau et al. 1994). The total integration time was 180 seconds in each band. Individual images were sky-subtracted, flatfielded, corrected for bad pixels and combined into a final mosaic. The uncorrected seeing was 0.6–1.0 arcsec, while the corrected resolution is ~ 0.15 arcsec. We used throughout the image scale of 34.38 ± 0.07 mas pixel^{-1} and rotation prescription from Rigaut et al. (1998b). The resulting orientation of the images is accurate to within 0.°1. The total field of view of the images shown here is 12.4 arcsec × 12.4 arcsec. Colour index images were made by combining the images after aligning the nuclear peak (in the absence of field stars). Although we were able to define the position of the nucleus accurately enough for alignment, the K-band profiles across the nucleus in the original exposures are flat, causing an artificial blue nuclear core in the $J-K$ and $H-K$ images. For this reason we do not discuss the area within the central arcsec of the $J-K$ image. The calibration of the images was performed in the standard way by observing stars from the list of Landolt (1983). The uncertainty in the calibration is about 0.05 mag.

We also present NIR and optical images with a larger field of view. The NIR images were taken with MONICA at the CFHT as part of a survey of galaxies with circumnuclear regions of star formation (Pérez-Ramírez & Knapen 1998; Knapen et al. 1999) and cover the central 1 arcmin × 1 arcmin with a resolution of 0.6 arcsec. An optical B-band image from the data archive of the Isaac Newton Telescope is also presented. The field of view is 10 arcmin × 10 arcmin, and the resolution 1.6 arcsec. Finally, we use a Faint Object Camera image from the *HST* archive, taken at an effective wavelength of ~ 2300 Å . The image covers the central 22 arcsec × 22 arcsec (Maoz et al. 1996).

3 RESULTS

The major axis diameter of the circumnuclear "ring" (CNR) of NGC 5248 (Fig. 1) is ~ 11 arcsec, or 800 pc. The SF "ring" is incomplete and patchy in UV emission. Some of the SF sites have been marked with letters A–F in Figures 1 and 2. Some weak and dilute emission can be seen within the nuclear area at radii within the "ring", but no SF spiral structure is visible, as confirmed by Isaac Newton Telescope archival Hα images (not shown here).

Table 1. Colour indices of the structures within the circumnuclear ring in magnitudes. The relative uncertainties are smaller than 0.03 mag.

Structure	$J-H$	$H-K$
Nucleus	0.72	
Nuclear spiral	0.85	0.15
Star formation "ring"	0.79	0.11

Figure 2 (left) shows our AO $J-K$ colour index image. Some of the SF regions of the circumnuclear "ring" are partly visible near the edges of the image, and show up as whitish patches. The most interesting feature in the image is the red (dark in the figure) spiral structure. Two arms with widths less than 1 arcsec (75 pc) originate at one arcsec northeast and southwest of the nucleus, and can be followed for 3 arcsec. They appear to end before the radius of the CNR (which is 5.5 arcsec). The two-armed spiral structure is trailing (assuming the spiral arms in the outer disk are trailing). Its red colour suggests that it is a dust spiral. We emphasize that the colour variations across the image are not large (Table 1). The contrast between the nuclear spiral and the regions immediately surrounding it is around 0.05 mag. The same two-armed spiral can be seen in $J-H$ and $H-K$ images, but it is most obvious in the $J-K$ image.

Figure 2 also shows the relation of the nuclear spiral structure to the outer disk of the galaxy. The right panel of Fig. 2 is the CFHT MONICA $J-K$ colour index image, made without AO. Only the inner part of the image, covering an area of 38 arcsec × 28 arcsec, is shown here. Again, red (dusty) spiral structure can be seen, most clearly just outside the nuclear starburst "ring", which is located very close to the edge of the AO image. Finally, in Fig. 3 we present the B-band image, showing the main optical spiral structure in the disk of NGC 5248, at radii of several kpc. Outside the central 2–3 arcmin region, a set of fainter spiral arms can be seen, extending out to at least 15 kpc (cf. Fig. 5 in Patsis et al. 1997).

Our broad-band AO J, H and K images show a variety of structure caused by SF regions, most clearly seen in J (Fig. 4) where the contributions of emission from young stars, but also of dust extinction, are largest. In all of the AO images, the strongest star formation region is clearly seen in the "ring" to the east of the nucleus. The position angle of the isophotes is $120^\circ \pm 10^\circ$, defined by the starburst ring, but the central 4 arcsec (300 pc) region is rounder than the region outside it. The FWHM of the nuclear peak is 0.7 arcsec. The nucleus is well defined in all images, and no double- or multiple-peaked structures exist.

Estimating the exact shape of the point spread function (PSF) in the various broad-band images is a difficult issue in AO imaging, and since in general different PSFs can give rise to artifacts in a colour index image, we have used two other, independent, techniques to confirm the existence of the red nuclear spiral. Both techniques were applied to the

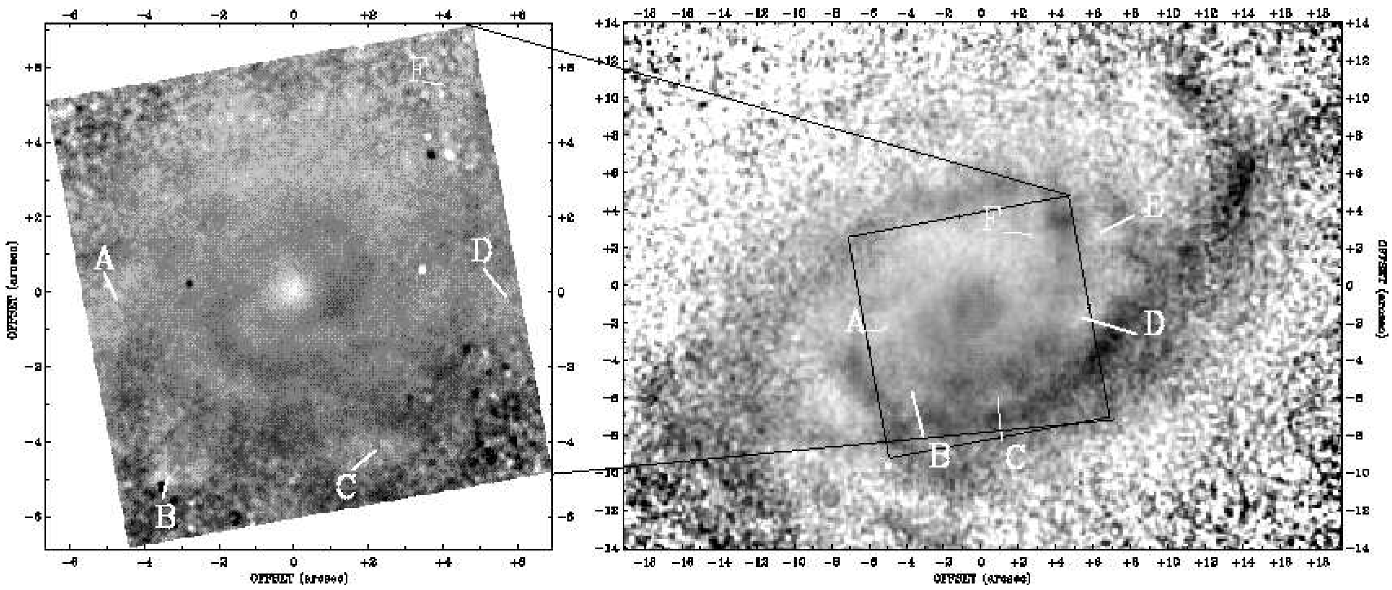

Figure 2. Left: CFHT adaptive optics $J-K$ colour index image of the core region of NGC 5248, showing the nuclear spiral in darker shades. The range of colours is approximately from 0.6 (lightest regions) to 1.2 (darkest). Some of the SF sites have been marked with capital letters to assist the comparison to the UV image (Fig. 1). Right: $J-K$ colour index image of a larger area around the central region of NGC 5248, as imaged in 1995 with the CFHT. The area of the nuclear image is shown with a box. The lightest colours have values around 0.8 whereas the darkest colours along the arms have values around 1.1. Again, some of the SF sites have been marked with letters A–F. North is up and east to the left in the images.

AO J band image. First, we used the unsharp-masking technique, whereby the J band image was smoothed to a resolution of 0.7 arcsec, and then subtracted from the original, unsmoothed, image. This technique may introduce artificial light and dark concentric circles, but our resulting image (Fig. 5) clearly shows the nuclear spiral arms as non-circular features. In a second test, we fitted ellipses to the isophotes of the J band image, built a model from the fitted ellipses, and subtracted the model from the original image. Again, the residuals reveal the nuclear spiral arms. Our tests thus confirm that the red nuclear spiral arms, as seen in the $J-K$ image, are not artifacts of the techniques used.

The colour index variations across the central 10 arcsec region are small (Table 1). Additionally, the residuals after subtracting a model of fitted ellipses reveal that the depletions in surface brightness in the J-band are only at about 5 per cent level when compared to the surrounding regions. Therefore, the (red) nuclear spiral is likely to be composed of dust and gas only, without a counterpart in the old or young stellar distribution.

Although we do not observe the nuclear spiral arms to connect to the CNR from inside, red spiral arms (right panel of Fig. 2) connect into the CNR from outside, and can be followed out to 10 arcsec radius. Near the locations of the outer ends of these red spiral arms, the main optical spiral structure begins, delineated by the bright SF regions seen in Fig. 3. The main strong SF spiral arms end near 70 arcsec from the nucleus, where Patsis et al. (1997) placed the dynamical 4/1 resonance. Beyond this distance, a set of fainter arms exists. In deeper exposures the faint arms appear as extensions of the main spiral structure (Chromey, Elmegreen & Harrison 1995). The gap, or the minimum in the spiral intensity, could well mark the corotation radius (Patsis et al. 1997).

4 DISCUSSION

In general, the most common tracers of spiral structure are bright, young, massive stars and the H II regions around them, most readily detected in optical Hα images (e.g., Sandage 1961). The underlying density enhancements, best seen in NIR K-band images where the effects of young stars and cold, extincting dust are much smaller than in the optical regime, show a smoother and more continuous variation in intensity between the arms and the interarm regions (e.g., Grosbøl & Patsis 1998). In this paper, we use different tracers of the spiral structure. The patchy spiral structure seen in the optical image in Figure 3 is made up of emission from young stars and SF regions, which have bluer colours than the surrounding disk of older stars. In contrast, the spiral structure seen in the NIR images is redder than its surroundings, tracing the reddening presumably caused by cold dust structures. In the $J-K$ image, the red colours may also have a small contribution from hot dust which begins to show up in the K-band at 2.2 μm.

Red, grand-design nuclear spiral arms, as reported here, have not been observed at such small scales before. In contrast, flocculent, dusty spiral arms and chaotic dust structures have been seen in the cores of several disk galaxies, both in the optical and in the NIR (see references in Introduction). What causes the nuclear grand-design spirals in NGC 5248?

The main optical spiral structure of NGC 5248 (Fig. 3) was modelled by Patsis et al. (1997). According to them, the main spiral exists between the dynamical inner Lindblad resonance (ILR) and the inner 4/1 resonance. In their model, the (outer) ILR occurs at a radius of 30–40 arcsec. In that case, the starburst "ring" at $r=5$ arcsec is located very far inside the radius of the outer ILR. It is unlikely that the

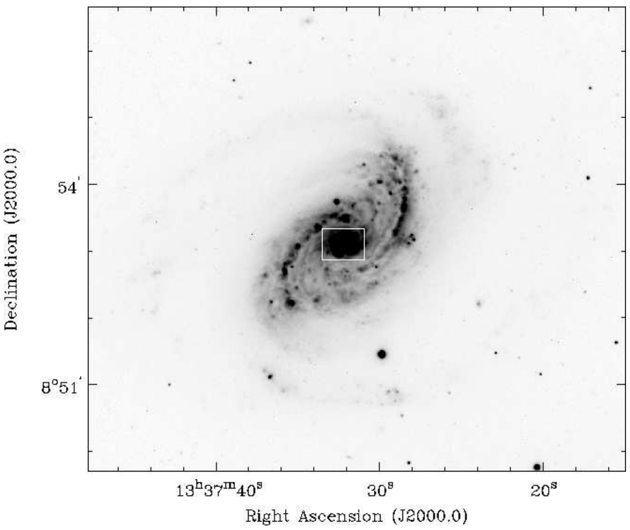

Figure 3. *B* band optical image of the disk of NGC 5248. A box indicates the area shown on the right of Fig. 2, demonstrating how the different scales interlock. Spiral structure is visible on all scales, from very close to the nucleus to far out in the disk.

nuclear trailing spiral structure in NGC 5248 is related to an inner ILR, as the spiral structure there would be expected to be leading (e.g., Knapen et al. 1995a; Combes 1996). High resolution kinematical data, combined with dynamical modelling, is needed for a definite study of dynamical resonance structures.

It is possible that a nuclear gas (and dust) disk exists around the core of NGC 5248. Small perturbations, such as massive gas clumps, will drive spiral structure in the gas disk, but it is unlikely that grand-design spirals can be generated by this mechanism. No nuclear bar can be seen within the SF “ring”, although the spiral structure could still be driven by an outer oval distortion. Nuclear gas disks have been seen recently in CO emission of some galaxies (e.g., Sakamoto et al. 1995; Laine et al. 1999), and high resolution observations of gas tracers in NGC 5248 are required to see if such a disk exists in NGC 5248.

Elmegreen et al. (1998) have suggested another possible mechanism for creating nuclear spiral structure. Acoustic spirals, generated by the amplification of sound waves at small galactocentric radii, may produce spiral-like waves. However, acoustic waves are likely to produce multiarmed spirals. Modes higher than $m = 2$ are weak or absent in our NIR images of the nuclear region of NGC 5248. Deeper imaging of the centre of NGC 5248 must be obtained to see whether $m > 2$ spiral structure exists, and thus whether acoustic spirals are a viable generating mechanism of the observed spiral structure.

Finally, it is possible that the spiral structure is continuous from about 1 arcsec radius to the outermost optical spiral arms. Recent modelling by Englmaier & Shlosman (in preparation) shows that a single ILR is capable of driving a two-armed spiral from corotation down to a few hundred pc or less from the nucleus. The CNR forms inside the single ILR because of the shock focusing and subsequent action of self-gravity in the gas. Deeper images with better signal to noise ratios are required to investigate the continuity of the spiral structure in NGC 5248.

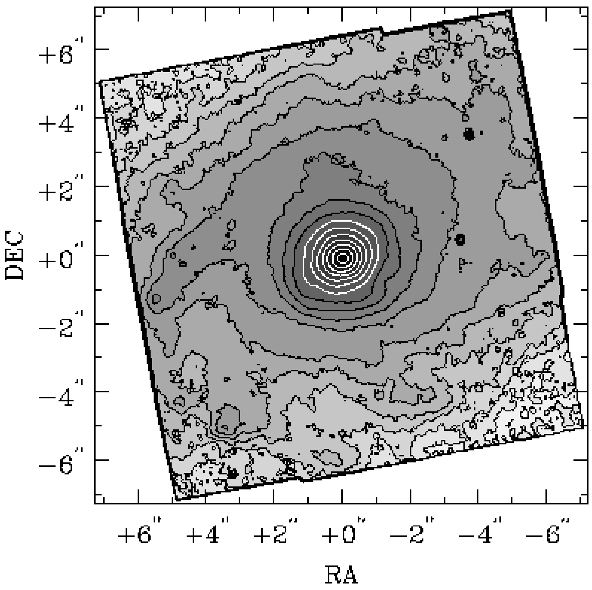

Figure 4. Adaptive optics *J*-band image with about 0.2 arcsec resolution as obtained at the CFHT. The grayscale and contour levels are from 13.5 to 16.9 mag arcsec^{-2}, in steps of 0.2 mag arcsec^{-1}. The contours near the nucleus have been drawn in white to indicate the lack of spiral or other features in a broad-band NIR image. The circumnuclear star formation ring shows up near the perimeter of the image.

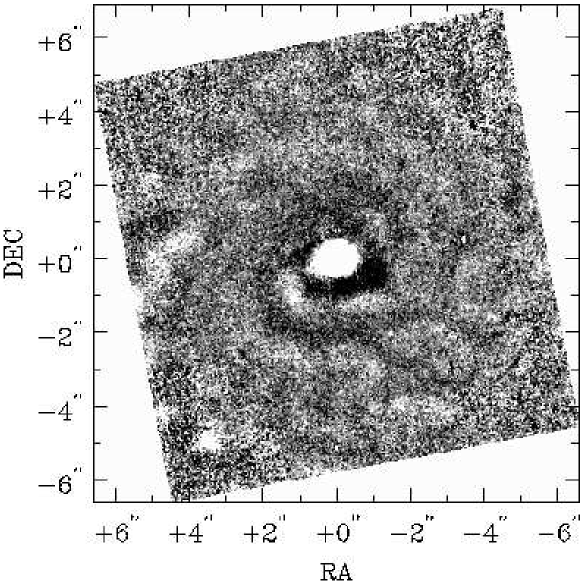

Figure 5. Unsharp-masked image in *J* band of the nuclear 12 arcsec x 12 arcsec region of NGC 5248.

5 CONCLUSIONS

We have detected a pair of red spiral arms in the central 100–300 pc region of NGC 5248. The nuclear grand-design spiral structure in NGC 5248 is real, and not an artifact of the observational techniques used. We have used three different techniques (a colour index image, unsharp masking, and subtraction of a model-based ellipse fit to the surface brightness distribution) to isolate the nuclear spiral from our broad-band NIR AO images, and confirm the spiral with all three techniques. It appears unlikely that the nuclear spiral is related to acoustic spirals. However, the dusty spirals may be an indication that a weak non-axisymmetric component exists and drives the grand-design spirals in a mildly gravitating nuclear gas disk. Sensitive, high resolution observations of the molecular and neutral gas would help to resolve the question of the origin of the nuclear spiral structure.

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