NUCLEAR PROPERTIES OF NEARBY SPIRAL GALAXIES FROM HUBBLE SPACE TELESCOPE NICMOS IMAGING AND STIS SPECTROSCOPY

M. A. Hughes, D. Axon, J. Atkinson, A. Alonso-Herrero, C. Scarlata, A. Marconi, D. Batchelor, J. Binney, A. Capetti, C. M. Carollo, L. Dressel, J. Gerssen, D. Macchetto, W. Maciejewski, M. Merrifield, M. Ruiz, W. Sparks, M. Stiavelli, and Z. Tsvetanov

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2 Centre for Astrophysical Research, Science and Technology Research Institute, University of Hertfordshire, Hatfield, Hertfordshire AL10 9AB, UK.

3 Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218.

4 School of Physics and Astronomy, University of Nottingham, University Park, Nottingham NG7 2RD, UK.

5 INAF-Osservatorio Astronomico di Torino, Via Osservatorio 20, I-10025 Pino Torinese, Italy.

6 INAF-Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, 50125 Florence, Italy.

7 Oxford University, Theoretical Physics, Keble Road, Oxford OX1 3NP, UK.

8 INAF-Osservatorio Astronomico di Torino, Via Osservatorio 20, I-10025 Pino Torinese, Italy.

9 INAF-Osservatorio Astronomico di Torino, Via Osservatorio 20, I-10025 Pino Torinese, Italy.

10 Department of Physics, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, NY 14623-5603.

11 IDegnoesische Technische Hochschule Zuerich, Hoenggerberg HPF G4.3, CH-8092 Zurich, Switzerland.

12 School of Physics and Astronomy, University of Nottingham, University Park, Nottingham NG7 2RD, UK.

13 Center for Astrophysical Sciences, Johns Hopkins University, 239 Bloomberg Center for Physics and Astronomy, 3400 North Charles Street, Baltimore, MD 21218.

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ABSTRACT

We investigate the central regions of 23 spiral galaxies using Space Telescope Imaging Spectrograph (STIS) spectroscopy and archival Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) imaging. The sample is taken from our program to determine the masses of central massive black holes (MBHs) in 54 nearby spiral galaxies. Stars are likely to contribute significantly to any dynamical central mass concentration that we find in our MBH program, and this paper is part of a series to investigate the nuclear properties of these galaxies. We use the Nuker law to fit surface brightness profiles, derived from the NICMOS images, to look for nuclear star clusters and find possible extended sources in three of the 23 galaxies studied (13%). The fact that this fraction is lower than that inferred from optical Hubble Space Telescope studies is probably due to the greater spatial resolution of those studies. Using R – H and J – H colors and equivalent widths of Hα emission (from the STIS spectra), we investigate the nature of the stellar population with evolutionary models. Under the assumption of hot stars ionizing the gas, as opposed to a weak active galactic nucleus (AGN), we find that there are young stellar populations (~10–20 Myr); however, these data do not allow us to determine what percentage of the total nuclear stellar population they form. In addition, in an attempt to find any unknown AGN, we use [N ii] and [S ii] line flux ratios (relative to Hα) and find tentative evidence for weak AGNs in NGC 1300 and NGC 4536.

Key words: galaxies: nuclei — galaxies: photometry — galaxies: stellar content

Online material: color figures

1. INTRODUCTION

The most impressive result from studies of massive black holes (MBHs) in recent years has been the discovery that the mass of the central black hole is correlated with other properties of the galaxy, such as bulge mass (e.g., Kormendy & Richstone 1995; Marconi & Hunt 2003) and stellar velocity dispersion (Ferrarese & Merritt 2000; Gebhardt et al. 2000). Consequently, it is prudent for any thorough investigation of MBHs to include a detailed study of the center of the galaxy in question. With this in mind, this paper forms part of a series in which we investigate the central regions of galaxies from our Hubble Space Telescope (HST) program to find MBHs in nearby spiral galaxies (GO: 8228, PI: D. Axon). The sample is limited to galaxies within a recessional velocity less than 2000 km s⁻¹ that are known to have Hα emission from ground-based observations. The good spectra and images and a description of the sample are presented in Hughes et al. (2003, hereafter H03) and Scarlata et al. (2004, hereafter S04). The first black hole mass estimates from the program are presented in Marconi et al. (2003) for NGC 4041 and Atkinson et al. (2005) for NGC 1300 and NGC 2748.

One aspect of galaxy centers that may have important consequences for black hole mass measurements is the presence of nuclear star clusters. HST observations have played a major role in showing that many (>50%) spiral galaxies have identifiable cores that are photometrically and morphologically distinct from the surrounding bulge (e.g., Böker et al. 2002; Carollo et al. 2002). Such compact luminous sources are generally believed to be nuclear star clusters, and in some cases, this has been demonstrated with spectroscopy (e.g., Böker et al. 2001; Walcher et al. 2003; Colina et al. 2002). The reason that these clusters may be important for black hole mass estimates is that invariably the region over which the central mass is determined includes the region occupied by the cluster. Thus, if the cluster mass is significant with respect to the black hole mass, then it needs to be taken into account.

Although quantifying the mass of the central stellar populations is beyond the scope of this paper, we attempt to determine other useful properties of the central regions of the galaxies.
Specifically, this paper is a companion to S04, in which we quantified the profile of the bulges from the STIS images using the Nuker law profile (Lauer et al. 1995) and looked for the presence of nuclear star clusters. The first aim of this paper is to reuse the Nuker profile and apply it to archival Near Infrared Camera and Multi-Object Spectrometer (NICMOS) images of galaxies from our sample. Since near-infrared images are not as affected by dust obscuration as the Space Telescope Imaging Spectrograph (STIS) images, these provide the opportunity of producing a clearer view of the central bulge and a better way of quantifying the shape of the bulge. The second purpose of this paper is to use the spectral information from our STIS program (H03) and archival NICMOS images in an attempt to quantify the age of the central stellar population.

The structure of this paper is as follows. In § 1.1 we describe the selection of the sample of spiral galaxies, the STIS spectroscopic observations, and the reduction of the archival NICMOS images. In § 2 we produce surface brightness profiles (SBPs) from the NICMOS images to look for central sources. In § 3 we investigate the ages of the stellar populations at the centers of galaxies using both color information from the NICMOS and STIS images and STIS spectroscopy.

### 1.1. The Sample Selection

The complete list of galaxies is presented in Table 1 in H03, and in Table 1 (this paper) we list those galaxies for which we were able to obtain archival NICMOS H-band images. All the galaxies are classified as late-type spiral galaxies and are nearby, having recessional velocities of less than 2000 km s\(^{-1}\).

The original purpose of the STIS images was to locate the exact position of the nucleus of each galaxy so that spectroscopic apertures could be accurately placed. Such “acquisition images” were taken using the F28XS0LP long-pass filter. They are optical (central wavelength 7230 Å) and are approximately equivalent to the R band. For each galaxy, two acquisition images were taken to acquire the nucleus, and three long-slit apertures were placed to determine the nuclear gas disk kinematics. The pixel size is 0.05 pixel\(^{-1}\), and the field of view is 5" × 5". Integration times of the images vary from 20 to 60 s. The STIS images were reduced by the Flight Software involving the subtraction of a single bias number and the removal of hot pixels (see chapter 8 of the STIS Instrument Handbook).

Spectra of the galaxy centers covered five emission lines, [N\(\text{II}\)] \(6549.9, \lambda 6584.6, [N \text{II}] \lambda 6558.3\), and [S\(\text{II}\)] \(\lambda \lambda 6718.3, 6732.7\). These spectra are being used to map the velocity fields of nuclear gas disks so that central mass concentrations can be measured. The spectra are described in more detail in H03. Briefly, for each galaxy three slits were placed, one on the brightest central source (presumed to be the nucleus, unless obscured by dust) with two other, parallel slits 0.1′ either side. In this paper, we use these spectra for another purpose, to estimate the age of stellar populations at the centers of the galaxies (see § 3).

The HST archive was used to search for NICMOS observations for the galaxies in our sample. We found NIC2 F160W images (1.60 μm, similar to a ground-based H-band filter) for 23 galaxies, and for six galaxies we found NIC2 F110W filter images (1.10 μm, similar to a ground-based J-band filter). Many of the images were observed as part of an HST snapshot program by members of our team and appear in Carollo et al. (2002). The pixel size of the images is 0.0076 pixel\(^{-1}\), which produces a field of view of 19′′×19′′. The images were taken as part of a number of programs, with integration times of between 384 and 640 s. The images were reduced using NicRed (McLeod 1997).

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### Table 1

| Galaxy Name | Morphological Type | Nuclear Activity | Rec. Vel. (km s\(^{-1}\)) | Inclination (deg) |
|-------------|--------------------|------------------|---------------------------|-----------------|
| NGC 157     | SAB(rs)bc          |                  | 1589                      | 55              |
| NGC 289     | SAB(rs)bc          |                  | 1451                      | 40              |
| NGC 1300    | (R')SB(s)bc        |                  | 1409                      | 49              |
| NGC 2748    | SAbc               | (H \(\alpha\))   | 1741                      | 73              |
| NGC 2903    | SB(s)0d            | H \(\alpha\) (H \(\alpha\)) | 626 | 56 |
| NGC 2964    | SAB(r)bc           | H \(\alpha\) (H \(\alpha\)) | 1446 | 58 |
| NGC 3259    | SAB(rs)bc          |                  | 1929                      | 63              |
| NGC 3310    | SAB(r)bc pec       | H \(\alpha\) (H \(\alpha\)) | 1208 | 31 |
| NGC 3949    | SA(s)bc            | H \(\alpha\) (H \(\alpha\)) | 1021 | 56 |
| NGC 4030    | SAB(s)bc           |                  | 1619                      | 19              |
| NGC 4258    | SAB(s)bc           | L/S1.9 (S1.9)    | 674                       | 72              |
| NGC 4303    | SAB(rs)bc          | H \(\alpha\)/S2 (H \(\alpha\)) | 1619 | 19 |
| NGC 4389    | SBr(s)bc pec       |                  | 940                       | 54              |
| NGC 4527    | SBr(s)bc           | H \(\alpha\)/L (T2) | 1776 | 70 |
| NGC 4536    | SBr(s)bc           | H \(\alpha\) (H \(\alpha\)) | 1846 | 59 |
| NGC 5005    | SBr(s)bc           | S2/L (L1.9)     | 1153                      | 67              |
| NGC 5054    | SA(s)bc            |                  | 1704                      | 54              |
| NGC 5055    | SA(rs)bc           | H \(\alpha\)/L (T2) | 726 | 56 |
| NGC 5248    | (R) SB(rs)bc       | S2/H \(\alpha\) (H \(\alpha\)) | 1248 | 51 |
| NGC 5879    | SA(rs)bc?          | L (T2/L2)       | 1049                      | 74              |
| NGC 6384    | SAB(r)bc           | L (T2)          | 1780                      | 60              |
| NGC 6951    | SAB(rs)bc          | L/S2 (S2)       | 1705                      | 42              |
| NGC 7331    | SA(s)bc            | L (T2)          | 992                       | 75              |
The data reduction involved subtraction of the first readout, dark current subtraction on a readout-by-readout basis, correction for linearity and cosmic-ray rejection (using FULLFIT), and flat-fielding. In-orbit darks with sample sequences and exposure times corresponding to those of the observations were obtained from other programs close in time. Generally, between 10 to 20 darks were averaged together (after subtraction of the first readout) for each sample sequence. If more than one exposure for a given galaxy was taken, the images were shifted to a common position using fractional pixel offsets and combined to create the final images. Since the images were well sampled, any loss in resolution through using this technique should not be significant.

2. SURFACE BRIGHTNESS PROFILES AND THE PRESENCE OF CENTRAL SOURCES

SBPs have been used as an important diagnostic for inferring the presence of resolved, central sources in galactic nuclei. Böker et al. (2002) presented SBPs derived from WFPC2 F814W images and found many well-resolved central sources. The presence of a central source is indicated by an inflection in the profile at small radii (see Fig. 1). Without spectroscopy, such as performed by Böker et al. (2001) on NGC 4449 (who found a 6–10 Myr stellar population) or Walcher et al. (2003), we cannot be confident of the nature of these central sources. However, the general assumption by most authors is that they are probably star clusters.

Over the past few years, analysis of central sources has been performed for a large number of disk galaxies using HST images, in particular, using WFPC1 (Phillips et al. 1996), WFPC2 (Carollo & Stiavelli 1998; Carollo et al. 1998), and NICMOS (Carollo et al. 2002; Seigar et al. 2002). The main inference of these studies has been that central sources are a common feature of galaxy centers.

2.1. Nuker Surface Brightness Profile Fits

We used the ELLIPSE program under IRAF\(^\text{14}\) to perform isophotal ellipse fitting on the NICMOS images, from which we produced SBPs. In each case we allowed position angle and ellipticity to vary but kept the position of the center fixed. The flux calibration of the NICMOS images was performed using conversion factors (from ADU s\(^{-1}\) to Jy) based on measurements of the standard star P330-E, taken during the Servicing Mission Observatory Verification program (M. J. Rieke 1999, private communication). Consequently, results from the ellipse fitting were converted to magnitudes per square arcsecond by

\[
m_{\text{fit}} = -2.5 \log \left( \frac{2.19 \times 10^{-6}}{1083} \text{ counts s}^{-1} \right) + 5 \log \text{(scale)},
\]

where scale is the plate scale and is 0.076 pixel\(^{-1}\). For our J-band calculations (see Table 4) we substituted the factor \(-2.5 \log (2.031 \times 10^{-9}/1775 \text{ counts s}^{-1})\) into the first part of equation (1). The uncertainty on the photometry is assumed to be 2%.

To minimize assumptions, we chose to \emph{not} mask out complicated structures such as star formation rings. SBPs from the NICMOS images of NGC 289, 2748, 2903, 3259, 3949, 4527, 4536, and 6384 have previously been produced, from the same raw NICMOS images, by Seigar et al. (2002). Since these galaxies are also in our sample, we redo the profile fitting here. This enables us to perform a check on the consistency between both results. Following Seigar et al. (2002), the SBPs were fitted with a Nuker law profile of the form introduced by Lauer et al. (1995):

\[
I(r) = 2^{(\beta-\gamma)/\alpha} \frac{r_0}{r} \gamma \left[ 1 + \left( \frac{r}{r_0} \right)^{-\alpha} \right]^{-\gamma-\beta}/\alpha ,
\]

where \(\beta\) indicates the steepness of the outer profile, \(\gamma\) measures the steepness of the inner profile, \(\alpha\) indicates the sharpness of the transition between these two profiles, and \(r_0\) is the point of this transition at which the SBP has a brightness of \(I_0\).

It is important to take proper account of the NICMOS point-spread function (PSF) when fitting the SBPs. This can be done by either deconvolving the images prior to the fit or convolving each model profile with a suitable PSF before the fit is made. Unfortunately, deconvolution tends to increase the resulting noise. For this reason, we chose to follow the latter method, which has also been favored by other authors recently (e.g., Seigar et al. 2002; S04). Consequently, the models were convolved with Tiny Tim–generated NICMOS PSFs (Krist et al. 1998) before attempts were made to fit the SBPs.

The fitting routine is fundamentally the same as the one we used in S04. Briefly, we constructed an IDL program that made use of the standard IDL procedure \textit{curvefit}, which minimizes \(\chi^2\) by using the Levenberg-Marquardt method to search for the best fit. The user is able to supply the inner radius at which the fit is started, as well as the PSFs that are convolved with the models before each fit is attempted. As in S04, rather than add an additional model to account for central sources, we varied the inner radial range until we arrived at a suitable fit that excluded the central region and only fit the bulge. In some cases (NGC 157 and NGC 5879) we could not clearly identify a resolved central source but still found that the fits were improved by varying the inner radius. Possible resolved central sources are treated separately in § 2.2.

The best profile fits are shown in Figs. 2–4. When possible, both the Seigar et al. (2002) fits (\emph{dotted lines}, converted to

\[^{14}\text{IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA, Inc., under cooperative agreement with the National Science Foundation.}\]
Fig. 2.—NICMOS SBPs for NGC 157, 289, 1300, 2748, 2903, 2964, 3259, and 3310. Filled circles are the SBPs found from fitting ellipses to the isophotes. Dashed lines are our Nuker law fits to the profile, and the dotted lines (NGC 289, NGC 2748, and NGC 2903) are the Nuker profile fits of Seigar et al. (2002), which have been convolved with our Tiny Tim (Krist et al. 1998)–generated PSFs.
Fig. 3.—NICMOS SBPs for NGC 3949, 4030, 4258, 4303, 4389, 4527, 4536, and 5005. The profiles have been fitted with a Nuker law. Dashed lines are our fits, and dotted lines (NGC 4527 and NGC 4536) are those of Seigar et al. (2002), which have been convolved with our Tiny Tim (Krist et al. 1998)–generated PSFs. Variations between the dotted lines and the SBPs are probably due to differing assumptions made during the isophotal ellipse fitting of the NICMOS images.
Johnson magnitudes) and our fits (dashed lines) are shown together. Following Seigar et al. (2002), we corrected for extinction using the data of Burstein & Heiles (1984).

Table 2 lists the parameters of the fits. For NGC 2964 and NGC 4389 we did not find a good fit to the SBP. In many cases, however, the SBP can be completely described by the Nuker law. Parameters from Nuker law fits performed by Seigar et al. (2002) are also included in the table. Usually we found the value of $\alpha$ to be poorly constrained. This is unsurprising since, in general, the range of points in the profile fits extends well beyond the break radius, $r_b$. This is important because as $r \gg r_b$, the factor $[1 + (r/r_b)^{\alpha}]^{(\gamma - \beta)/\alpha}$ tends to become independent of $\alpha$.

The main reason for the differences in this work and that of Seigar et al. (2002) is the shape of the SBPs. While this is due in part to the decision as to whether the profiles should be smoothed and which regions to mask, it may also be due to the subjective choices (e.g., fixing ellipticity) that have to be made when performing the isophote fits. An example of the necessary subjectivity in SBP fitting can be seen for NGC 2748. We originally interpreted the profile as showing evidence for a nuclear cluster and so start the fit at an inner radius of $0''68$. In contrast, Seigar et al. (2002) start the profile fit inward of this, and so it is unsurprising that the Nuker parameters should be different. Generally, a decision has to be made for each profile as to the region where the Nuker profile is valid. This should be in between any central source and the region where the galactic disk dominates. We are assuming that the Nuker profile, which Lauer et al. (1995) originally proposed to describe elliptical galaxies, is actually a good description of the bulges in spiral galaxies. In some cases it is an overcomplicated description of the bulge profile, while in other cases structure in the profile can produce a wide range of parameters, depending on the subjective choice as to the region over which the fitting is performed (see also Graham et al. 2003). It is also important to note that dust could give the misleading impression that a cluster is present. For example, if we observe a SBP such as that shown in Figure 1, we must be careful that the inflection between the apparent bulge and central source profile is not in reality a result of dust obscuration.

It is useful to compare which central sources we detect, or fail to detect, with the results we presented in S04. For four of the galaxies, NGC 4536, 5054, 6384, and 6951, we found central...
sources in the STIS profiles (shown in Table 3 of S04), yet adequate Nuker law fits are made in Figures 3 and 4 without the need to invoke the presence of a star cluster. There are several possibilities to explain why this situation might arise: (1) The population could be blue and hence not readily visible in the NICMOS images. (2) The presence of dust in the STIS images may have given us the misleading impression of a cluster being present. (3) An older, redder population may dominate the NICMOS images to an extent that the cluster is not visible. (4) The lower resolution of the NICMOS images may have smoothed out any image of the cluster.

The presence of central sources seems clear for NGC 2748, 3949, 4030, and 4303, where a well-sampled$^{15}$ upturn in the profile in the NICMOS images is present. However, closer inspection of the NICMOS images in Figure 5 shows that dust is the likely cause of the inflection in the SBP for NGC 2748. This highlights the problem of using just the SBP to find central sources. Central sources for all of the remaining galaxies were previously reported in S04, although only the cluster in NGC 4030 was identified as resolved in that paper.$^{16}$ A central star cluster has also been identified for NGC 4303 by Colina et al. (2002), who find a 3.1 pc cluster of 4 Myr in age. In Figure 6 the SBPs are compared with the NICMOS PSF and appear to be resolved. In these cases, if the Nuker law describes the underlying galactic light, the magnitude of the central source can be extracted.

\[ I_P(r) = \frac{L}{\pi b^2} \left(1 + \frac{r^2}{b^2}\right)^{-\gamma}. \]

Here $I_P$ is the total luminosity of the central source, and $r$ is the radius from the center of the source. We do not directly measure $b$; instead, we determine the FWHM from Gaussian fits to the central sources. To convert our results to the half-light radius $b$, we repeat the method described in S04. Briefly, we established the relationship between the Gaussian FWHM and $b$ by simulating multiple central sources of known $b$. These artificial images of star clusters were convolved with a NICMOS PSF, and

\[ b = \text{FWHM}_{\text{Gauss}} \times \text{FWHM}_{\text{PSF}}. \]

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Notes.—The Nuker law parameters as defined in eq. (2). Range is the region, in arcseconds, over which the fits were made. The $I_P$ values have been corrected using Burstein & Heiles (1984) results. The values in parentheses are taken from Seigar et al. (2002) (S02) and are presented here for comparison. The quoted uncertainties are $1\sigma$.

2.2. Quantifying the Size and Luminosity of the Central Sources

We attempted to quantify the size and luminosity of the central sources. Specifically, the techniques we used are similar to those described in S04, which were derived from the analysis of Carollo et al. (1998). The results are shown in Table 3. In summary, the luminosity of the central source is bounded by the results from two methods. In the first method a Gaussian profile is fit to each central source using the IRAF task $n2gaussfit$. This task also calculates the background, and so we produced background-subtracted model Gaussian central sources, from which the luminosity could be determined. In the second method, the profile fits from Table 2 were used to produce model images of the galaxy bulges. These were then subtracted from the original galaxy images, and the luminosity of the central source was determined by using an aperture size of approximately 2FWHM of the central source.

As in S04, we used the Plummer law to determine the half-light radius, $b$, of the central sources:

\[ I_P(r) = \frac{L}{\pi b^2} \left(1 + \frac{r^2}{b^2}\right)^{-\gamma}. \]

Here $I_P$ is the total luminosity of the central source, and $r$ is the radius from the center of the source. We do not directly measure $b$; instead, we determine the FWHM from Gaussian fits to the central sources. To convert our results to the half-light radius $b$, we repeat the method described in S04. Briefly, we established the relationship between the Gaussian FWHM and $b$ by simulating multiple central sources of known $b$. These artificial images of star clusters were convolved with a NICMOS PSF, and
the FWHMs were determined in the same way as the actual images. The uncertainties on \( b \) were found by varying the sides of the box, over which the Gaussians were fitted to the original images, by \( \pm \frac{C_6}{2} \) pixel.

3. THE AGE OF THE CENTRAL STELLAR POPULATIONS

The main goals of our STIS project are to understand the nature of the central regions of a sample of nearby late-type spiral galaxies and to determine whether the galaxies host a black hole in their centers. Using the STIS spectroscopic data, we are carrying out detailed modeling of the central velocity field of the nuclear disks in our sample of galaxies to infer the central mass concentrations. Before we can conclude that the central mass is a black hole, we need to determine whether such a central mass concentration could be accounted for by a stellar population.

As a first step toward finding the masses of the central stellar populations, we need to quantify their ages. Because of the difficulties in identifying nuclear clusters from the NICMOS images and since some star clusters may be present but completely hidden by the bulge light, we decided to examine the
### Table 3

**Properties of the Central Sources**

| Galaxy          | $M_H$ (mag) | $M_R$ (mag) | $b$ (pc) | $b_R$ (pc) | FWHM (arcsec) | FWHM ($R$) (arcsec) |
|-----------------|-------------|-------------|----------|------------|---------------|---------------------|
| NGC 3949........ | $-14.1 \pm 0.2$ | $-1.7 \pm 0.4$ | PS       | 0.17       | ...           | ...                 |
| NGC 4030........ | $-16.6 \pm 0.2$ | $-14.0 \pm 0.3$ | $7.6 \pm 0.2$ | 0.32       | 0.16          | ...                 |
| NGC 4303........ | $-18.0 \pm 0.2$ | $-4.5 \pm 0.2$ | PS       | 0.19       | ...           | ...                 |

**Notes.**—Col. (1): The name of the galaxy. Col. (2): The absolute $H$-band magnitude. Col. (3): The equivalent absolute STIS $R$-band magnitude from S04. Col. (4): The half-light radius from the Plummer law shown in eq. (3). Col. (5): The half-light radius from S04. PS means point source. Col. (6): The FWHM from the Gaussian fits. Col. (7): The FWHM from S04. Note that values from S04 have been converted using $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

### Table 4

**Magnitudes within a Circular Aperture and EWs of Hα**

| Galaxy          | $R$ (50 pc) | $R$ (100 pc) | $R(a)$ (50 pc) | $R(a)$ (100 pc) | $R-H$ (50 pc) | $R-H$ (100 pc) | $J-H$ (50 pc) | $J-H$ (100 pc) | $R-H(a)$ (50 pc) | $R-H(a)$ (100 pc) | $J-H(a)$ (50 pc) | $J-H(a)$ (100 pc) | $\text{EW}(\text{Å})$ $\text{EW}(\text{Å})$ |
|-----------------|-------------|--------------|----------------|-----------------|---------------|---------------|---------------|---------------|-----------------|-----------------|-----------------|----------------|-----------------|----------------|
| NGC 289.......... | 18.40       | 17.38        | 18.98          | 17.93           | 3.61          | 3.61          | 1.14          | 1.17          | 20.1 (0.5)      | 18.6 (0.3)      | ...             | ...             | ...             | ...             |
| NGC 1300......... | 17.47       | 16.51        | 18.07          | 17.25           | 3.15          | 3.15          | 3.11          | ...           | ...             | ...             | ...             | ...             | ...             | ...             |
| NGC 2748......... | 17.61       | 16.57        | 18.14          | 17.16           | 3.31          | 3.31          | 3.24          | 3.18          | ...             | ...             | 10.6 (1.1)      | 16.7 (0.3)      | ...             | ...             |
| NGC 2903......... | 16.80       | 15.68        | 17.32          | 15.90           | 3.55          | 3.55          | 3.45          | 3.31          | ...             | ...             | 9.3 (0.1)       | 12.6 (0.2)      | ...             | ...             |
| NGC 2964......... | 17.61       | 16.57        | 18.14          | 17.16           | 3.31          | 3.31          | 3.24          | 3.18          | ...             | ...             | 10.6 (1.1)      | 16.7 (0.3)      | ...             | ...             |
| NGC 3259......... | 19.65       | 18.62        | 20.15          | 19.12           | 3.72          | 3.72          | 3.88          | 3.23          | ...             | ...             | 53.8 (0.7)      | 37 (1)          | ...             | ...             |
| NGC 3310......... | 16.42       | 15.47        | 16.92          | 16.59           | 3.92          | 3.92          | 3.86          | 3.93          | 0.93            | 0.92            | 75 (1)          | 75 (1)          | ...             | ...             |
| NGC 3949.......... | 18.08       | 17.04        | 18.68          | 17.41           | 3.64          | 3.64          | 3.61          | 3.66          | 0.87            | 0.89            | ...             | ...             | ...             | ...             |
| NGC 4030.......... | 17.83       | 16.85        | 18.47          | 17.29           | 3.10          | 3.10          | 3.19          | 3.15          | ...             | ...             | 2.43 (0.06)     | 2.66 (0.04)     | ...             | ...             |
| NGC 4258.......... | 15.08       | 14.18        | 15.79          | 14.92           | 3.14          | 3.14          | 3.02          | 2.93          | 0.97            | 0.96            | 29.1 (0.4)      | 24.1 (0.4)      | ...             | ...             |
| NGC 4303.......... | 16.22       | 15.59        | 17.47          | 16.61           | 3.71          | 3.71          | 3.11          | 3.03          | ...             | ...             | 5.7 (0.9)       | 6.9 (0.1)       | ...             | ...             |
| NGC 4536.......... | 17.52       | 16.51        | 18.01          | 17.22           | 4.18          | 4.18          | 4.12          | 4.03          | ...             | ...             | 1.29 (0.02)     | 1.86 (0.03)     | ...             | ...             |
| NGC 5005.......... | 16.07       | 14.88        | 16.34          | 15.40           | 3.63          | 3.63          | 3.34          | 3.37          | ...             | ...             | 12.1 (0.2)      | 8.7 (0.4)       | ...             | ...             |
| NGC 5054.......... | 17.93       | 16.92        | 18.52          | 17.50           | 3.47          | 3.47          | 3.51          | 3.35          | ...             | ...             | 3.07 (0.08)     | 3.35 (0.08)     | ...             | ...             |
| NGC 5055.......... | 14.44       | 13.85        | 15.63          | 15.17           | 3.78          | 3.78          | 3.69          | 3.83          | ...             | ...             | ...             | ...             | ...             | ...             |
| NGC 5248.......... | 17.25       | 16.29        | 17.84          | 17.03           | 3.08          | 3.08          | 3.19          | 3.20          | ...             | ...             | 4.40 (0.08)     | 3.8 (0.1)       | ...             | ...             |
| NGC 5879.......... | 17.76       | 16.62        | 18.18          | 16.94           | 3.25          | 3.25          | 3.13          | 2.95          | ...             | ...             | 3.0 (0.1)       | 2.26 (0.03)     | ...             | ...             |
| NGC 6384.......... | 18.71       | 17.46        | 19.02          | 17.75           | 3.23          | 3.23          | 3.13          | 3.11          | 0.97            | 0.99            | ...             | ...             | ...             | ...             |
| NGC 6951.......... | 17.64       | 16.71        | 18.30          | 17.35           | 3.54          | 3.54          | 3.64          | 3.60          | 1.07            | 1.12            | 12 (1)          | 13 (1)          | ...             | ...             |
| NGC 7331.......... | 15.07       | 14.19        | 15.83          | 14.97           | 3.17          | 3.26          | 3.26          | 3.20          | ...             | ...             | 1.32 (0.08)     | 1.01 (0.02)     | ...             | ...             |

**Notes.**—Magnitudes calculated within circular apertures. The diameters of the apertures are given in parentheses. The expression $R(a)$ indicates that the magnitudes are found for annuli of area equivalent to a circular aperture of the given diameter; e.g., “$R(a) 50$ pc” is the magnitude within an annulus that begins at 25 pc from the nucleus and has an area equivalent to a 50 pc circular aperture. The last two columns denote the EWs of Hα for the sum of the signal within square apertures with sides of 50 and 100 pc, respectively.
central stellar population within two arbitrary, but small, apertures of diameters 50 and 100 pc. Galaxies for which no obvious central source was seen in the NICMOS SBP are also included. The magnitudes within these circular apertures, plus magnitudes within annuli of the same area directly surrounding the apertures, are shown in Table 4.

The near-infrared data are useful for investigating the masses of stellar populations for two main reasons. First, the extinction in the $H$ band is greatly reduced in comparison with that in the optical ($A_H = 0.175 A_V$; Rieke & Lebofsky 1985). Second, the infrared mass-to-light ratios are less dependent on the galaxy properties than the optical ones. Still, they can vary by a factor of 2 (see, e.g., Bell & de Jong 2001), so an estimate of the age of the stellar population is necessary.

We used Starburst99 (Leitherer et al. 1999) evolutionary synthesis models. Our goal is not to constrain the initial mass function (IMF), so we used just the standard Salpeter IMF with an upper mass cutoff of $M_{up} = 100 M_\odot$. The model assumes solar metallicity and instantaneous star formation. For the six galaxies with two observed colors ($R - H$ and $J - H$), we can plot a two-color diagram and compare with the model outputs. The NICMOS magnitudes are measured in the Johnson photometric system, whereas the STIS acquisition magnitudes are given in the STMag photometric system. We have used the Starburst99 spectral energy distribution outputs to convert the STIS acquisition magnitudes to the $R$ band using the SYNPHOT package in IRAF.

As can be seen from Table 4, there is no strong variation of the color whether the 50 or 100 pc aperture is used. Figure 7 shows the $R - H$ against $J - H$ colors for the 100 pc aperture size. The time evolution for ages between 1 Myr (lower left corner) and 20 Myr (in intervals of 1 Myr) and for 30 and 40 Myr are shown for the model described above. For reference the reddest values for the $R - H$ color occur for ages of between 9 and 12 Myr, which correspond to the epoch when the first supergiants appear and start contributing significantly to the light in the $H$ band.

We also show in this diagram the effect of 1 mag of extinction. The reddening vector is almost parallel to the model, and so with the right amount of extinction the points could fit a variety of ages. Clearly, the $R - J$ and $J - H$ colors alone cannot be used to constrain the age of the stellar population.

A better way to constrain the age of the stellar population is to use the equivalent width (EW) of H$\alpha$. Table 4 shows the EW within square apertures defined by sides of 50 pc (or 100 pc) and the slit width of 0$''$.2. As can be seen from Figure 8 in Leitherer et al. (1999), for instantaneous star formation the EW of H$\alpha$ decreases with time. Figure 8 shows the $R - H$ color against H$\alpha$ EW. Here we plot the data for the 14 galaxies with measured colors and EWs. Again, the evolution is shown for ages between 1 and 20 Myr (in 1 Myr intervals) and 30 and 40 Myr. Note that in this case the extinction vector only affects the color, because we are assuming that the extinction to the stars and the gas is the same, and thus the EW of the line is independent of the extinction. The H$\alpha$ EW allows the ages of the stellar population to be constrained. We can also infer the extinction to the central 100 pc. The typical values for our sample are $A_V = 1-2$ mag. The derived ages of the central sources (they are mostly independent of the model assumed) are typically between 10 and 15 Myr, except for NGC 3310, for which the age is 6–7 Myr.

The case of continuous star formation was ruled out, since the Starburst99 (Leitherer et al. 1999) simulations indicate that the EW of H$\alpha$ should remain greater than 146 Å, which is not the case for any of the galaxies in our sample. We also believe that the case of an older stellar population plus continuous star formation is not the case in the central regions because of the similarity in colors in both 50 and 100 pc apertures.

Note, however, that the underlying assumption is that all the ionizing photons come from stars. If an active galactic nucleus (AGN) were present, then this would tend to increase the EW...
and give the impression that a stellar population was actually younger than its real age. We cannot unambiguously rule out previously unknown AGNs in the galaxies in our sample. As a check, using our data we compared the line ratios of both [N \text{ii}] λ6550, 6585 and [S \text{ii}] λ6718, 6732 to that of H\textbeta λ6565. The results are presented in Table 5. Two possible additional weak AGNs, indicated by the relatively high values of the [N \text{ii}] ratios, are NGC 1300 and NGC 4536. It should also be noted that the galaxies with known activity in our sample have EWs that are well spread throughout the distribution of EWs (e.g., EW = 24.1 ± 0.4 \text{ Å} for NGC 4258 and EW = 1.01 ± 0.02 \text{ Å} for NGC 7331). In summary, while we think it is unlikely that the EWs are dominated by ionization from weak nuclear activity, we cannot rule it out with this data set.

4. SUMMARY

Using NICMOS images, we constructed SBPs, to which we fitted Nuker laws to search for the presence of nuclear star clusters. Several of the images had previously been fit by Seigar et al. (2002), and there is some variation in their resultant Nuker parameters when compared with ours, partly due to the necessary subjectivity in performing the fits. In four cases, NGC 2748, 3949, 4030, and 4303, there appears to be an excess that cannot be accounted for by the Nuker profile alone. In the case of NGC 2748, the apparent excess is misleading and is probably due to obscuring dust causing an inflection in the SBP. However, for the latter three galaxies, the excesses are likely to be real and may be due to the presence of nuclear star clusters.

Although star clusters and AGNs can coexist (e.g., Colina et al. 2002), we attempted to identify any unknown AGNs by using [N \text{ii}] and [S \text{ii}] line flux ratios (relative to H\textbeta) and found tentative evidence for weak AGNs in NGC 1300 and NGC 4536.

As a first step toward constraining the ages of the central stellar populations, we used color information from the STIS and NICMOS images and the EW of H\textbeta for the STIS spectra and compared these data to the stellar evolutionary models of Leitherer et al. (1999). The EW of H\textbeta was the important factor, as it constrained the ages to ~10 Myr, provided that the ionization of the disk was primarily due to the central stellar population. To confirm the age of the population, we would need to perform spectroscopy on the galaxy centers.

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