THE NICMOS SNAPSHOT SURVEY OF NEARBY GALAXIES

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Received 1998 October 21; accepted 1999 April 8

ABSTRACT

We present “snapshot” observations with the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) on board the Hubble Space Telescope (HST) of 94 nearby galaxies from the Revised Shapley Ames Catalog. Images with 0′2 resolution were obtained in two filters, a broadband continuum filter (F160W, roughly equivalent to the H band) and a narrowband filter centered on the Pa line (F187N or F190N, depending on the galaxy redshift) with the 51′ × 51′ field of view of the NICMOS camera 3. A first-order continuum subtraction is performed, and the resulting line maps and integrated Pa line fluxes are presented. A statistical analysis indicates that the average Pa line brightness is highest in early-type (Sa–Sb) spirals.

Subject headings: galaxies: nuclei — galaxies: starburst — galaxies: statistics — galaxies: structure — infrared: galaxies — infrared: ISM: lines and bands

1. INTRODUCTION

NICMOS is a second-generation HST instrument, installed during the HST servicing mission in 1997 February. It extends the wavelength region accessible for imaging and spectroscopy with HST to the near-infrared (NIR), up to λ = 2.5 μm.

Shortly after its on-orbit installation, it was discovered that the NICMOS Dewar suffered from a thermal anomaly that led to a higher than expected sublimation rate of the solid nitrogen coolant, and thus a shorter than anticipated lifetime. In addition, the mechanical deformation of the Dewar prevents parfocality of the three NICMOS cameras, to the extent that NIC3, the camera with the widest field of view (51′ × 51′), can only be brought fully to focus by moving the secondary mirror of the HST. This, on the other hand, prevents observations with the other HST instruments which is why it was decided to concentrate all approved NIC3 observations in “campaigns” of 2–3 weeks duration. Two of these campaigns have been successfully executed half a year apart to allow all-sky access.

In order to fill any gaps in the observing schedule during the NIC3 campaigns with meaningful scientific data, a “snapshot” survey was proposed and approved to be undertaken with Director’s discretionary time (proposal ID 7919). The data were made public soon after the observations and can be retrieved from the HST archive. The scientific rationale behind the project was to obtain wide field imaging of the Pa emission for as many galaxies of the Revised Shapley Ames Catalog (RSA; Sandage & Tammann 1987) as allowed by the scheduling efficiency of the NIC3 campaigns.

Since the NIR is much less affected by dust extinction than optical wavelengths, the NIR is well suited for probing the heavily obscured central regions of spiral galaxies. The Pa line at 1.875 μm is a recombination line of atomic hydrogen, and as such is indicative of the ionized matter around hot, newly formed stars or active galactic nuclei (AGNs). It lies in a wavelength region subject to strong atmospheric absorption by H₂O molecules and is therefore accessible for ground-based observations only with great difficulty. NICMOS provides two narrowband filters in the NIC3 camera that are suitable for Pa observations: the F187N filter was used for all galaxies with a radial velocity v_r between −1295 and 943 km s⁻¹, while galaxies with 3181 ≤ v_r ≤ 4780 km s⁻¹ were observed with the NIC3 F190N filter. The velocity range was chosen such that the Pa line falls well inside the high transmission region of the respective filter, with only minor corrections (≤5%) needed to account for the highest velocities with respect to the filter central wavelength.

For continuum subtraction, each galaxy was also observed in the F160W filter which approximately spans the H band from 1.4 to 1.8 μm.

2. THE SAMPLE

The galaxy sample was selected at random from the RSA according to scheduling convenience. Ninety-four galaxies were observed in total, 64 of which lie in the low-redshift range, and 30 in the higher. Sorted by Hubble type, the sample contains 17 galaxies classified as E or S0, 20 Sa/Sab/Sb’s, 39 Sbc/Sc’s, and 18 Scd/Sd/Sm/Irregulars. The sample thus should be large enough to be a fair representation of the RSA and its distribution of Hubble type and luminosity. Table 1 lists the observed galaxies.

3. OBSERVATIONS AND DATA REDUCTION

The observations were performed using the MULTI-ACCUM STEP64 sampling sequence as described in the NICMOS instrument handbook (MacKenty et al. 1997). All F160W continuum images were taken with NSAMP = 11 for a total integration time of 192 s. The F187N and F190N line emission images had values for NSAMP between 13 and 25, yielding integration times between 320 and 1088 s. Column (5) of Table 1 contains the narrowband integration time.

For data reduction, the calibrated (*.cal.fits) FITS images as retrieved from the HST archive were used as a starting point. These images have been dark-subtracted, flat-fielded, and cosmic-ray-corrected in an automated way.

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| NGC    | Type       | AGN? | $v_e$ (km s$^{-1}$) | $t_{int}$ (s) | $F_{PAW}$ ($\times 10^{-21}$ W cm$^{-2}$) | $D_{25}/51^*$ | PAW ? |
|--------|------------|------|---------------------|--------------|--------------------------------------|--------------|-------|
| 128    | S0(8)pec  |      | 4253                | 896*         | <0.1                                 | 3.5          | ...   |
| 151    | SBC(rs)   |      | 3741                | 704*         | 10.6                                 | 4.4          | RSN   |
| 214    | Sbc(r)    |      | 4499                | 704*         | 12.0                                 | 2.2          | S,N   |
| 221    | E2        |      | -200                | 832          | 46.7                                 | 10.3         | ...   |
| 237    | Sc(s)     | $S^b$| 4139                | 768*         | 18.5                                 | 1.9          | S     |
| 247    | Sc(s)     |      | 156                 | 448          | 8.2                                  | 25.3         | I     |
| 404    | S0(0)     | $L^2$| -39                 | 576          | 16.8                                 | 4.1          | N     |
| 491    | SBC(rs)   |      | 3899                | 704*         | 43.8                                 | 1.7          | S     |
| 598    | S0(7)pec  | S   | -180                | 896          | 21.3                                 | 83.5         | DN    |
| 628    | S0(8)pec  |      | 656                 | 576          | 5.7                                  | 12.4         | I     |
| 672    | SBc(s)    | H   | 413                 | 1088         | 20.0                                 | 8.5          | I     |
| 891    | Sbc(rs)   |      | 530                 | 960          | 147.2                                | 15.9         | DL    |
| 976    | Sbc(rs)   | H   | 564                 | 756          | 13.1                                 | 12.4         | I     |
| 1241   | E2        |      | 4362                | 512*         | 22.6                                 | 1.8          | S,N   |
| 1705   | Am.       |      | 640                 | 576          | 5.2                                  | 2.2          | I,DN  |
| 2314   | E3        |      | 3872                | 704*         | 9.9                                  | 2.0          | N     |
| 2366   | SBm       |      | 98                  | 1088         | 6.9                                  | 9.6          | I     |
| 2403   | Sc(s)     | H   | 131                 | 640          | 20.0                                 | 25.8         | I, DN |
| 2639   | Sa        | S1.9b| 3187                | 640*         | 9.6                                  | 2.1          | R,N   |
| 2642   | SB(rs)    |      | 4439                | 576*         | 9.8                                  | 2.4          | S,N   |
| 2672   | E2        |      | 3983                | 384*         | <0.1                                 | 3.5          | ...   |
| 2683   | Sa        | L1.9*| 715                 | 576          | 24.3                                 | 4.2          | N     |
| 2685   | SB(s)     | L2/S2*| 404               | 896          | 32.9                                 | 11.0         | S,DL,N|
| 2749   | E3        |      | 4229                | 896*         | 5.9                                  | 2.0          | N     |
| 2787   | SB0/a     | L1.9*| 664                 | 960          | <0.1                                 | 3.8          | ...   |
| 2841   | Sb        | L2*  | 637                 | 768          | 11.6                                 | 9.6          | N     |
| 2903   | Sc(s)     | H   | 550                 | 704          | 74.5                                 | 14.9         | R,JDN,DL|
| 2942   | Sc(s)     |      | 4414                | 704*         | 12.7                                 | 2.6          | I     |
| 2976   | Sd        | H   | 13                  | 512          | 14.4                                 | 7.0          | I,N   |
| 2989   | Sc(s)     | H2b  | 4166                | 960*         | 6.5                                  | 2.0          | S,N   |
| 2998   | Sc(rs)    |      | 4777                | 512*         | 7.7                                  | 3.4          | SJ    |
| 3077   | Am.       |      | 7                   | 832          | 66.5                                 | 6.4          | DN    |
| 3184   | Sc(r)     | H   | 589                 | 960          | 6.4                                  | 8.7          | NJ    |
| 3271   | Sa        |      | 3824                | 1088*        | 13.1                                 | 3.7          | N     |
| 3275   | SBB(r)    |      | 3241                | 640*         | 16.7                                 | 3.3          | N     |
| 3379   | E0        | L2/T2:*| 893               | 704         | <0.1                                 | 6.4          | ...   |
| 3517   | SA       |      | 3777                | 896*         | <0.1                                 | 3.5          | ...   |
| 3593   | S pec     | H   | 625                 | 320          | 57.0                                 | 6.1          | S, RN |
| 3627   | Sbb(a)    | T2/S2*| 723               | 640         | 23.5                                 | 11.4         | NJ    |
| 3675   | Sbr      | T2*  | 762                 | 832          | 26.1                                 | 7.0          | SJ    |
| 3738   | Sd        | H   | 224                 | 896          | 11.6                                 | 3.0          | I, DN |
| 3769   | Sbc(s)    |      | 737                 | 512          | 17.7                                 | 3.7          | I     |
| 3782   | Sbc(s)    |      | 738                 | 832          | 6.6                                  | 2.0          | I     |
| 4373   | E1        |      | 878                 | 768          | 3.4                                  | 6.1          | DN    |
| 4389   | Sc(s)     | H   | 772                 | 576          | 14.3                                 | 4.8          | I     |
| 4402   | Sc        |      | 753                 | 768          | 44.0                                 | 3.3          | S,N   |
| 4411   | Sbr(r)pec | H   | 865                 | 704          | 98.8                                 | 3.5          | S,N   |
| 4436   | Sc(r)     | H   | 445                 | 832          | 2.4                                  | 4.7          | S,N   |
| 4514   | Sed       | H   | 265                 | 704          | 6.5                                  | 7.1          | I     |
| 4518   | Scd       | H   | 355                 | 512          | 13.8                                 | 6.0          | I     |
| 4526   | Sed       | H   | 931                 | 576          | 4.1                                  | 7.4          | I     |
| 4530   | Sm        |      | 231                 | 704          | 6.5                                  | 2.0          | I, DN |
| 4592   | Sb        | T2*  | -140                | 640          | 12.4                                 | 11.6         | S     |
| 4728   | E1       | L1.9*| 630                 | 704          | 12.2                                 | 4.8          | N     |
| 4923   | Sa        | L2*  | 933                 | 768          | 11.6                                 | 6.6          | NJ    |
| 4924   | Sbc(s)    |      | 352                 | 704          | 22.8                                 | 3.8          | S     |
| 4929   | Sd(s)     |      | 232                 | 640          | 23.5                                 | 2.0          | I, DN |
| 4373   | E(4,2)    |      | 3444                | 896*         | 8.0                                  | 4.0          | N     |
| 4389   | SBC(s)pec |      | 717                 | 896          | 20.3                                 | 3.1          | NJ    |
Bad Pixels

Residual bad pixels in the CALNICA processed image are due to three possible defects:

1. Remaining cosmic-ray hits that are not detected by the CALNICA pipeline.

2. Defective (i.e., “hot” or “dead”) pixels on the NIC3 detector are also not replaced during pipeline processing because the images were not dithered and no meaningful observational data exist for these pixels.

3. Caused by mechanical contact due to the NICMOS Dewar anomaly, small flecks of antireflective paint have been scraped off one of the optical baffles. Some of these have migrated onto the NICMOS detector surfaces. These flecks, known as “grot,” result in small areas (one to a few pixels) of reduced sensitivity. Since the grot might be subject to unpredictable movement on the detector, it is currently not included in the bad pixel mask for CALNICA. However, recent results have shown that the grot has been quite stable over time, and plans exist to include the affected pixels in the next version of the CALNICA bad pixel masks.

Since the point spread function (PSF) is undersampled in the NIC3 camera, it is not straightforward to discriminate between uncorrected bad pixels and real point sources in the pipeline processed data. We created a mask that defined as bad all pixels that showed a deviation greater than 4 $\sigma$ from the mean flux, where $\sigma$ is the estimated uncertainty. To minimize contamination of real point sources in the mask, we used commands from the PSF image, if present—nuclear (N), H II regions in a spiral arm structure (S), a ring (R), or isolated throughout the disk (I), diffuse nebulosities (DN), or dust lanes (DL).}

TABLE 1—Continued

| NGC (1) | Type (2) | AGN? (3) | $v_t$ (km s$^{-1}$) (4) | $t_{bad}$ (s) (5) | $F_{Pa_a}$ ($\times 10^{-21}$ W cm$^{-2}$) (6) | $D_{25,51}^*$ (7) | $Paz$ ? (8) |
|---------|---------|---------|----------------------|----------------|-----------------------------------------------|------------------|-----------|
| 4395    | Sd      | S1.8    | 317                  | 320            | 5.2                                           | 15.6             | N         |
| 4417    | S0(7)   |         | 843                  | 448            | <0.1                                          | 4.0              | ...       |
| 4449    | Sm      | H       | 207                  | 1024           | 107.3                                         | 7.3              | 1, DN     |
| 4490 (VV 30) | Scd pec | H*      | 570                  | 768            | 43.1                                          | 7.4              | N, I, DN   |
| 4559    | Sc(s)   | H*      | 810                  | 576            | 28.0                                          | 12.6             | I         |
| 4571 (IC 3588) | Sc(s) |         | 343                  | 704            | 0.3                                           | 4.2              | I         |
| 4605 (IC 4705) | Sc(s) | H*      | 141                  | 960            | 17.6                                          | 6.8              | 1, DN     |
| 4701    | Sbc(s)  |         | 724                  | 1024           | 14.4                                          | 3.3              | S         |
| 4786    | E3      |         | 4647                | 704*           | 10.6                                          | 1.9              | N         |
| 4826 (M64) | Sab(s) | T2*     | 413                  | 320            | 69.1                                          | 11.8             | S, DL     |
| 5055 (M63) | Sbc(s) | T2*     | 503                  | 512            | 45.8                                          | 14.9             | S, I, DL   |
| 5444    | E3      |         | 3974                | 960*           | 4.9                                           | 2.8              | N         |
| 5474 (VV 344) | Scd(s) pec | H*    | 275                  | 576            | 5.6                                           | 5.7              | 1, DN     |
| 5585    | Sd(s)   | H*      | 304                  | 576            | 3.2                                           | 6.8              | 1, DN     |
| 5605    | Sc(rs)  |         | 3363                | 640*           | 6.4                                           | 1.9              | I         |
| 5641    | SBab    |         | 4467                | 576*           | 3.6                                           | 3.0              | N         |
| 5653    | Sc(s)   |         | 3557                | 512*           | 50.4                                          | 2.0              | S         |
| 5908    | Sb      |         | 3312                | 384*           | 33.9                                          | 3.8              | S, DL     |
| 6207    | Sc(s)   | H*      | 846                  | 832            | 33.2                                          | 3.5              | I         |
| 1C 4710 | SBd(s)  |         | 700                  | 448            | 2.9                                           | 4.2              | N         |
| 6684    | Sb(s)   |         | 886                  | 768            | 14.1                                          | 4.7              | N         |
| 6699    | Sbc(s)  |         | 3509                | 704*           | 9.2                                           | 1.8              | N, S, I   |
| 6744    | Sbc(s)  |         | 833                  | 832            | 3.4                                           | 23.6             | N         |
| 6754    | Sbc(s)  |         | 3325                | 512*           | 15.4                                          | 2.2              | N, S, I   |
| 6808    | Sc(s)   |         | 3466                | 576*           | 33.0                                          | 1.8              | S, I      |
| 6822 (IC 4895) | Im |         | -49                  | 512            | 14.9                                          | 18.3             | I         |
| 6876    | E3      |         | 3971                | 384*           | <0.1                                          | 3.3              | ...       |
| 6946    | Sc(s)   | H*      | 48                   | 768            | 109.5                                         | 13.6             | S, N, I   |
| 1C 5052 | Sd      |         | 307                  | 832            | 27.0                                          | 7.0              | I         |
| 7309    | Sc(rs)  |         | 3938                | 1024*          | 10.3                                          | 2.2              | N, S, I   |

Notes—Col (1): NGC number and possible alternative names. Cols. (2) and (4): morphological type and recession velocity, respectively, as taken from the RSA (Sandage & Tammann 1987). Col. (3): type of nuclear activity—H II nucleus (H), Seyfert nucleus (S), LINER (L or S3), and transition object (T). Numbers attached to the class letter designate the type; “+” and “−” denote uncertain and highly uncertain classifications. Galaxies that appear in neither of these catalogs have no entry. Col. (5): integration time for the narrowband filter (F190N with an asterisk, F187N otherwise). Col. (6): total $Paz$-flux in the field of view. Col. (7): ratio of optical diameter $D_{25}$ taken from de Vaucouleurs et al. 1976 to the NIC3 field of view of 51¢. Col. (8): morphology of the excess emission in the Pa A image, if present—nuclear (N), H II regions in a spiral arm structure (S), a ring (R), or isolated throughout the disk (I), diffuse nebulosities (DN), or dust lanes (DL).

a Adopted from Ho et al. 1997a.

b Adopted from Veron-Cetty & Veron 1998.
files that are used by CALNICA are not a perfect representation of the actual instrumental bias and dark current, because some or all of the components that contribute to the dark signal are time variable. These variations are believed to be driven by subtle temperature changes in the electronics and/or the detectors themselves. Typical pixel amplitudes are a few data numbers (DN) up to about 15 DN, but larger values have been occasionally observed.

The effect of a residual bias in the image after dark current subtraction is that multiplication with the flat-field reference file leaves an imprint of the relative pixel sensitivities in the resultant image. To further complicate the matter, the four quadrants of each NICMOS detector have separate amplifiers and readout electronics. Therefore, the pedestal typically is different in each quadrant of a NICMOS image.

To correct the data for the pedestal effect, we have used code developed at STScI by R. van der Marel. The code assumes a constant bias in each detector quadrant, which is a good approximation in most cases. In brief, the program determines the value of this bias by minimizing the spread of the pixel values in each quadrant. The rationale behind this method is that any nonzero bias increases the spread because the image is multiplied by the (inverse) flat-field during CALNICA processing. The software and a description of the algorithms used are available from the WWW.²

For fields that are largely filled by the science object, as is the case for the data set presented here, the method of spread minimization performs better than other methods like simple median subtraction or large-scale structure removal.

After the bias value has been determined for each quadrant, the scaled flat-field is subtracted from the image, and the four quadrants are brought to match. The last step is difficult to do in an automated way, especially if the galaxy nucleus—which typically has a very steep gradient in its signal—is located close to quadrant borders. Any residual “edges” in the images presented in § 4 are due to shortcomings in the quadrant equalization step and can be improved manually by adding small constants to each quadrant.

### 3.3. Continuum Subtraction

To subtract the continuum underlying the Paα line emission in the narrowband filter images, the following approach was taken.

Both the F160W and F187N/F190N images were rebinned to a size of 128 × 128 pixels for the purpose of reducing both the scatter and the total number of data points in the plot. We then plotted the intensity (in DN) of each pixel in the rebinned F160W image versus that of the same pixel in the rebinned F187N/F190N image. If the galaxy had constant color over the field of view and no Paα emission, the relation should be linear down to the noise level. Deviations from the linear relation can be due to intrinsic color variations, differential extinction effects, Paα line emission, or a combination thereof.

We then performed a linear least squares fit to the data points, the slope of which should be the scaling factor between the two filters. In most cases, all pixels were used for the fit, excluding the bottom 10 rows in the original images, since these are subject to vignetting and contain no reliable information. In addition, the 500 brightest pixels in the F187N/F190N image were excluded, because those pixels typically contain either foreground stars, bright H II regions, or the galaxy nucleus. Therefore, they do not provide a good estimate for the average color of the image. Finally, the F160W image was scaled by the slope of the linear fit, and the result subtracted from the F187N/F190N image in order to obtain a map of the excess emission. Although it is not possible to discriminate between the various contributions to the excess emission, as mentioned above, we refer to the resulting images as Paα maps for the remainder of this paper in order to simplify the terminology. We also point out that if a smoothly distributed component of Paα emission is present, it will be removed by this procedure, thus leading to an underestimate of the total Paα flux. Also, no attempt was made to correct for the PSF differences between the two filters because the NIC3 PSF is undersampled in both filters.

Figure 1 contains the F160W images, the Paα maps, and the fit results for all galaxies of the sample after the described data reduction. The plot of the flux distribution gives a visual impression of the complexity of the galaxy color distribution or, correspondingly, the reliability of the continuum scaling factor. For most early-type galaxies, e.g., NGC 2314 or NGC 2681, the scatter around the linear best fit is small. In principle, a higher fraction of ionized gas causes larger scatter. In nearby galaxies where many individual stars are resolved (e.g., NGC 247 or NGC 4144), the scatter is largest because of the color distribution of the stars. However, a mere shift of the solid line indicating the best fit does not affect the quantitative results. This is because a possible offset is removed when measuring the Paα signal, as described in § 3.4.

Based on the Paα images of Figure 1, a rough morphological classification of the galaxy sample was performed. In column (8) of Table 1, each galaxy is labeled according to the presence of one or more of the following features: unresolved or extended Paα emission from the galaxy nucleus (N), individual H II regions located in a spiral arm structure (S), a ring (R), or isolated throughout the disk (I), diffuse nebulosities (DN), or prominent dust lanes (DL). For most of these labels, we feel confident that they indeed contain information on the distribution of real Paα emission. The only exception is the often observed signal from the nucleus of the galaxy. Whether this is true Paα emission or the effect of a color gradient can only be answered with additional spectral information. A slight spatial offset between the two images or the small PSF differences between the filters might also lead to residual asymmetric signal in the nuclei, if they have very steep brightness profiles. However, the edgelike color gradients observed in some nuclei like NGC 2683 or NGC 4373 are probably real, since stars in the field subtract out almost perfectly, and the structure is too extended to be caused by PSF mismatches. In summary, the label “N” in Table 1 indicates that the Paα image shows increased signal in the nucleus without specifying its nature.

A number of objects show an obvious oversubtraction in the nucleus. This is a direct consequence of the simplistic “one-color” approach taken here if the continuum emission in the center has a bluer color than in the disk. The most likely explanations for a bluer color of the nucleus are enhanced star formation or the presence of an AGN. A more detailed case-by-case study, possibly with additional

² http://sol.stsci.edu/marel/software/pedestal.html.
Fig. 1—F160W image (top), Pas image (center), and results of the continuum fit (bottom) for all galaxies of the sample. North and east are indicated in the upper right corner of the F160W image. The field of view for all images is $51'' \times 51''$, the resolution is 0.2. In the plots, the 100 brightest pixels in the F160W are not shown to optimize the plot range.
Fig. 1 — Continued
NGC 2841 – Sb

NGC 2787 – S0/a

NGC 2740 – E3

NGC 2685 – S0(7) pec
Fig. 1.—Continued
FIG. 1.—Continued
Fig. 1—Continued
Fig. 1—Continued
Fig. 1—Continued
FIG. 1.—Continued
color information, should allow a better continuum subtraction in the nuclei, but it is beyond the scope of this paper due to the large data volume.

3.4. \(^3\alpha \) Fluxes

In order to compare the star formation properties of the galaxy sample, the integrated \(^3\alpha \) flux was calculated from the line maps. A first step checked for any systematic offsets in the maps by calculating the mode of pixel values in an empty region of the \(^3\alpha \) map. The mode should be close to zero after the described data reduction procedure, if the linear fit for the continuum was correct. In cases where a (small) offset was present, the mode was subtracted to bring the \(^3\alpha \) “background” to zero.

An automated method was developed to sum the total \(^3\alpha \) flux in the line maps which is briefly described here. Continuum oversubtraction would seriously affect the result when simply adding all pixels in the \(^3\alpha \) map. The image was therefore clipped at a certain threshold and only the signal above this level was summed. One complication to this method is that some images have a number of pixels above the noise level that apparently do not contain true line emission. This is particularly true for images that were taken after an HST passage through the South Atlantic Anomaly (SAA). The effect of a cosmic particle hit on the NICMOS detectors is equivalent to a higher dark current and the uncertainty regarding the signal nature made no attempt to correct for the position of the line with the uncertainty significantly to the described uncertainties, as explained in § 3.3. However, a more detailed analysis on a case-by-case basis should be possible, e.g., by comparing \(^3\alpha \) equivalent widths with predictions from stellar population synthesis models. A few general comments can still be made from the images alone.

4.1. Star Formation in the Galaxy Disks

From the images in Figure 1, it is evident that \(^3\alpha \) emission in the disks of most spiral galaxies traces the spiral arm structure. This is expected since the denser environment in the spiral arms is known to cause enhanced star formation. The line emission is clumpy, unlike the generally smooth stellar continuum. This matches similar results obtained at ultraviolet wavelengths which also trace active star formation (e.g., Waller et al. 1997). However, the UV morphology is hampered by strong dust extinction. The question is whether star formation is clumpy because of how stars form or because of how dust obscures. In this context, the relatively dust-insensitive \(^3\alpha \) morphology in our images confirms earlier claims that star formation is intrinsically clumpy. Early-type galaxies generally show little or no line emission in their disks, but often have strong emission from their central regions. A notable exception is NGC 1241, an Sb spiral with a Sy 2 nucleus, which shows an inclined ring of star formation about 7” in diameter surrounding the nucleus. At the distance of the galaxy (80 Mpc for \(H_0 = 50\) km s\(^{-1}\) Mpc\(^{-1}\)), this corresponds to 2.7 kpc.

The clumps of \(^3\alpha \) emission lose their organized distribution when going from late type spirals to irregular galaxies, and their typical size becomes larger. The strongest \(^3\alpha \) emission is found in starburst galaxies like NGC 3077, NGC 3593, or NGC 4449, to name a few. A special case is NGC 1705. This metal-poor, almost dust-free dwarf galaxy contains a very UV bright super star cluster, which has very little nebular gas emission (Meurer et al. 1995). This is an effect of the cluster age of about 13 Myr. At this stage, the hottest cluster stars are no longer ionizing the surrounding interstellar matter. However, the strong stellar winds observed to come out of the galaxy are believed to be a consequence of the past activity of the cluster (Heckman & Leitherer 1997). They might also be responsible for the extended, low-level star formation in the outer regions of the galaxy that is evident in the \(^3\alpha \) image.

A number of highly inclined galaxies in the sample show strong dust lanes even in the NIR. Examples are NGC 891, and also NGC 2683 and NGC 5908. The dust lane in NGC 891 is so opaque that the differential extinction in the two filters causes strong residual signal in the \(^3\alpha \) map. This extreme case demonstrates the problem of disentangling color effects from true line emission.

4.2. \(^3\alpha \) Surface Brightness and Star Formation Rates

It is customary to use the surface brightness (SB) of hydrogen recombination lines, in particular the H\(_z\) line, as a measure for the star formation rate of the galaxy. Studies along these lines at UV and optical wavelengths (e.g., Kennicutt 1983; Kennicutt & Kent 1983; Deharveng et al. 1994; Young et al. 1996) resulted in the notion that star formation in later Hubble types is on the average higher than in earlier types.
These studies were performed over apertures that included the whole visible disk of the galaxy. In contrast, the NIC3 field of view of 51' × 51' in all cases does not contain the full disk, especially for the nearby galaxies. This is evident from column (7) of Table 1, which lists the ratio $D_{25}$ to the NIC3 field of view. Since it is unknown what fraction of the total Pa$\alpha$ emission lies outside the NIC3 field, it is not possible to derive the average over the whole galaxy disk. Therefore, one can only draw conclusions for the central 51' of the galaxies and thus might expect slightly different results for the variation of star formation rate with Hubble type than derived from the earlier studies. The Pa$\alpha$ flux from Table 1 was converted into an average surface brightness $SB_{\text{Pa}\alpha}$ according to

$$SB_{\text{Pa}\alpha} \left[ L_\odot \text{ pc}^{-2} \right] = 5 \times 10^{18} F_{\text{Pa}\alpha} \left[ \text{W cm}^{-2} \right].$$

Here the constant $5 \times 10^{18}$ results purely from unit conversions, the mean value of $SB_{\text{Pa}\alpha}$ is independent of galaxy distance. Following the approach of Young et al. (1996), each of the four panels in Figure 2a contains histograms of $SB_{\text{Pa}\alpha}$ for the full sample of 94 galaxies (dashed line) in comparison to a subset of Hubble types, namely (i) E–S0, (ii) Sa–Sb, (iii) Sbc–Sc, and (iv) Scd–Irr. The median $SB_{\text{Pa}\alpha}$ for all galaxies in the respective subset is indicated by a star symbol. As found by the earlier studies, the scatter in the histograms is large. We also confirm the generally low star formation activity in Ellipticals and S0’s, about an order of magnitude fainter than the values found for spirals and irregulars.

As for the spirals and irregulars in our sample, we do not see the monotonic increase of $SB_{\text{Pa}\alpha}$ between Sa and Sm that Young et al. (1996) found for Hz. Rather, we find that $SB_{\text{Pa}\alpha}$ decreases slightly between Sa and Sm. This result remains basically unchanged if all galaxies with redshifts above 945 km s$^{-1}$ (those observed with the F190N filter) are excluded (Fig. 2b). For the full sample, Sa’s to Sb’s show a median (mean) $SB_{\text{Pa}\alpha}$ that is 53% (64%) higher than Sbc’s and Sc’s.

The images of our sample are dominated by the central regions of the galaxies. This follows from the fact that the average $D_{25}$ is larger than the field-of-view (9.1 times the NIC3 field for the F187N sample, compared to 2.7 for the F190N sample, col. [7] in Table 1). Therefore, our finding of a higher $SB_{\text{Pa}\alpha}$ in the centers of early-type galaxies can be understood if the fraction of ionized gas in their nuclei is higher than in late types. A similar notion was made by Young et al. (1996) who also found that a substantial fraction of the H$\alpha$ emission in early Hubble types stems from the nucleus. This result can be interpreted as a direct consequence of the more likely existence of an AGN in early-type spirals. A large fraction of the early-type (Sb or earlier) galaxies in our sample (15 out of 47) show indications of a Seyfert- or LINER-type nucleus, while only a small fraction (2 out of 47) of late types (Sc or later) are classified as AGNs. Thus, a compact AGN exists preferentially in the core of early-type spirals, its contribution would increase the ionized gas fraction relative to a galaxy without an AGN. Therefore, this result does not mean that nuclear star formation is weaker in late-type spirals but reflects the observational result that luminous AGNs avoid late spirals and irregulars, as found by Ho, Filippenko, & Sargent (1997b). In fact, many Sc’s or Sd’s reveal signs of massive gaseous inflow toward their nuclei, as will be shown in the next section.

4.3. Nuclear Star Formation and Gas Dynamics

Active star formation occurs in regions where the molecular gas is dense enough to become gravitationally unstable. The strong star formation that is often observed in the nuclear regions of galaxies requires some mechanism that causes large amounts of molecular gas to fall into the central few hundred parsecs of the galaxy.

![Fig. 2. Histograms of the Pa$\alpha$ surface brightness for various Hubble types. (a) Results for the full sample. (b) Results for only those galaxies with redshifts less than 945 km s$^{-1}$. For each histogram, the results for the full sample of 94 galaxies is indicated by the dashed line for comparison. The median SB for all galaxies in the respective subset is indicated by a star symbol.](image-url)
The most commonly evoked process by which the gas can lose its angular momentum is that of dynamical resonances of the gas orbits in the nonaxisymmetric potential of a stellar bar. Various compelling theoretical arguments indicate that bars in galaxies are indeed an efficient mechanism for channeling gas from the outer to the nuclear regions of spirals (Shlosman, Begelmann, & Frank 1990; Athanassoula 1992; Buta & Combes 1996). According to these models, nuclear star-forming rings and disks are expected by-products of gas inflow toward the inner regions in barred spirals at the locations of the inner Lindblad resonances (ILRs). These nuclear rings are also thought to be an integral part of the gas dissipation processes which ultimately lead to the fueling of AGNs and possibly to the formation of central black holes. Massive nuclear disks are themselves subject to nonaxisymmetric dynamical instabilities which drive the gas further inward by means of gravitational torques, possibly leading to the formation of nested bars and fueling stellar and nonstellar activities in the center (Shlosman, Frank, & Begelmann 1989).

The unprecedented spatial resolution of the NICMOS data allows us to investigate such processes in more distant galaxies than possible from ground-based observations. Figure 3 contains a collection of some of the more interesting galaxies in our sample that reveal complex gas distributions like double peaks, spirals, bars, rings or arcs in

FIG. 3.—Overlay of the Paα (gray scale) and continuum (contours) emission of the central regions for nine sample galaxies with central gas concentrations. The images have been median filtered over a 3 × 3 box.
the Pa$_{a}$ images. All of them are Sbc or later spirals. In Figure 3, we compare the Pa$_{a}$ (gray scale) and continuum (contours) emission from the nuclear region. To emphasize the extended structure, all images have been median filtered over a $3 \times 3$ box. In many cases in Figure 3, like, e.g., NGC 2989, NGC 6754, or NGC 6946, the continuum contours are elongated. This is unlikely a pure projection effect, and emphasizes that the prominent stellar bars found in many early-type spirals can indeed have weaker counterparts in late Hubble types. High spatial resolution NIR studies, together with molecular line observations of a number of nearby galaxies like, e.g., M83 (Handa et al. 1990; Gallais et al. 1991), NGC 253 (Peng et al. 1996; Böker, Krabbe, & Storey 1998), NGC 4570 (van den Bosch & Emsellem 1998), or IC 342 (Ishizuki et al. 1990; Böker, Förster-Schreiber, & Genzel 1997), have shown that massive gas inflows—presumably triggered by dynamical resonances with a stellar bar—fuel active star formation in the central few tens of parsecs. It is likely that the gas morphologies seen in Figure 3 are caused by similar processes.

5. SUMMARY

We have presented near-infrared continuum and Pa$_{a}$ images of the centers of 94 nearby galaxies of all morphological types. The unprecedented spatial resolution of the data reveals remarkable activity and a wealth of structure in many of the galaxies.

We have mapped the gas morphology in the galaxy nuclei and found in many cases evidence for gas infall, most likely triggered by dynamical interaction with a stellar bar. We also have performed a statistical analysis of the average Pa$_{a}$ surface brightness $SB_{pa}$ over the NIC3 field. The main result is that $SB_{pa}$ in the central regions is on the average stronger in Sa and Sb galaxies than in later Hubble types, most likely due of the higher fraction of AGNs in early-type spirals.

The catalog is intended to serve as a database for further study of individual objects, their star formation activity, dynamics, and matter distribution. The data are available electronically from the HST archive (Prop. 7919), and we encourage all interested colleagues to take advantage of them.

We are grateful to our anonymous referee whose comments helped a great deal to improve the quality of this paper. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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