PREVALENCE OF TIDAL INTERACTIONS AMONG LOCAL SEYFERT GALAXIES: THE CONTROL EXPERIMENT

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ABSTRACT

We test whether there is a relation between the observed tidal interactions and Seyfert activity by imaging in atomic hydrogen (H i) 27 inactive galaxies at the same spatial resolution and detection threshold as the Seyfert sample. This control sample of inactive galaxies was closely matched in Hubble type, range in size, and inclination and has roughly comparable galaxy optical luminosity to the Seyfert galaxies. We find that only ~15% of the galaxies in our control sample are disturbed in H i, whereas the remaining ~85% show no disturbances whatsoever in H i. Even at a spatial resolution of ~10 kpc, none of the latter galaxies show appreciable H i disturbances reminiscent of tidal features. In a companion paper we report results from the first systematic imaging survey of Seyfert galaxies in H i gas. We find that only ~28% of the 18 Seyfert galaxies in that sample are visibly disturbed in optical starlight. By contrast, ~94% of the same Seyfert galaxies are disturbed spatially and usually also kinematically in H i gas on galactic scales of ~20 kpc. In at least ~67% and up to perhaps ~94% of cases, the observed disturbances can be traced to tidal interactions with neighboring galaxies detected also in H i. The dramatic contrast between the observed prevalence of H i disturbances in the Seyfert and control samples implicates tidal interactions in initiating events that lead to luminous Seyfert activity in a large fraction of local disk galaxies.

Subject headings: galaxies: active — galaxies: interactions — galaxies: ISM — galaxies: Seyfert —
galaxies: structure

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1. INTRODUCTION

Active galactic nuclei (AGNs) are believed to be manifestations of the vigorous accretion of gas onto a central supermassive black hole (SMBH). The origin or source of this gas, as well as how it is brought into the sphere of influence of the SMBH, is one of the long-standing unresolved problems in AGN research (for a recent brief review, see, e.g., Martini 2004). Only a very small fraction (roughly 1%) of galaxies in the local universe exhibit luminous AGNs, although an appreciable fraction may exhibit nonstellar nuclear activity at some level.

One of the most popular hypotheses for triggering luminous AGNs is gravitational interactions between galaxies. Observational studies of local AGNs have mostly focused on optically selected samples of Seyfert galaxies. Seyfert galaxies are preferentially found among early-type spiral galaxies and exhibit very broad emission lines (from their nuclei) compared with their inactive counterparts. Although most Seyfert galaxies do not appear to be visibly disturbed, let alone interacting in optical starlight, some studies report that Seyfert galaxies more frequently possess projected or genuine neighboring galaxies (within a given angular separation) compared with matched samples of inactive galaxies (e.g., Stauffer 1982; Dahari 1984; Rafanelli et al. 1995; Dultzin-Hacyan et al. 1999; Koulouridis et al. 2006). This may constitute indirect evidence for more frequent interactions between Seyfert galaxies and their neighboring galaxies than their visual appearances would suggest. On the other hand, there also are studies that refute reports of any differences between the frequency of Seyfert and inactive galaxies with projected neighboring galaxies (e.g., MacKenty 1989; Fuentes-Williams & Stocke 1988; de Robertis et al. 1998b; Schmitt 2001).

Studies of nearby galaxies have demonstrated that atomic hydrogen (H i) gas can reveal tidal features not visible in optical starlight (e.g., Yun et al. 1994). Because the H i disk of normal spiral galaxies usually extends nearly twice as far out as the stellar optical disk, the outer regions of the H i disk are more loosely gravitationally bound. The H i disk is therefore more susceptible to external gravitational perturbations than the stellar optical disk, and when perturbed the outskirts also take longer to dynamically relax. This makes H i the most sensitive and enduring tracer known of gravitational interactions between galaxies. To directly address whether Seyfert galaxies are involved in galaxy-galaxy interactions, we have therefore, for the first time, imaged uniformly a relatively large sample of Seyfert galaxies in H i gas. The full
results of that study are presented in a companion paper by Kuo et al. (2008). Here we compare the results of Kuo et al. (2008) with those obtained for a matched sample of inactive galaxies, i.e., a control sample.

To select a control sample, we apply the lessons learnt from optical studies that address whether galaxy-galaxy interactions are responsible for triggering Seyfert activity (see, e.g., discussions in Fuentes-Williams & Stocke 1988; de Robertis et al. 1998b; Dultzin-Hacyan et al. 1999). A number of the especially earlier studies select as their control sample the closest (in projected separation) inactive galaxies with sizes comparable to the Seyfert galaxy (e.g., Dahari 1984; MacKenty 1989; Rafanelli et al. 1995). As pointed out by Dultzin-Hacyan et al. (1999), if Seyfert galaxies lie at or close to the center of a local galaxy density enhancement, a control sample selected in this manner may then systematically lie in a region of lower galaxy density. Consistent with this possibility, MacKenty (1989) finds that a larger fraction of Seyferts have projected neighboring galaxies than comparable sized inactive galaxies lying in the relatively close vicinity, but not with those selected at random across the sky.

The more recent optical studies select at random inactive galaxies with the same morphological (i.e., Hubble) type and redshift, and sometimes also size and absolute magnitude, as the Seyfert galaxies. This matching is made either on a one-to-one basis (e.g., de Robertis et al. 1998a) or over the range of properties observed (e.g., Dultzin-Hacyan et al. 1999). As pointed out by both Fuentes-Williams & Stocke (1988) and Dultzin-Hacyan et al. (1999), matching in absolute magnitudes may systematically bias the control sample to higher luminosities because of the nonnegligible contribution from the AGN. An exact match to the absolute magnitude of the Seyfert galaxy minus its AGN contribution is usually not possible as such measurements are not generally available, but it is desirable to the degree possible (e.g., as in de Robertis et al. 1998b). By minimizing the differences in galaxy properties between the Seyfert and control samples, it is hoped that a meaningful comparison of their environments will be possible, although this is not obviously the case. Using this method, de Robertis et al. (1998b) find no significant excess of projected neighboring galaxies between their Seyfert and control samples and at best only a marginal difference between their light asymmetries. On the other hand, Dultzin-Hacyan et al. (1999) find an excess of Seyfert 2, but not Seyfert 1, with projected neighboring galaxies compared with their control sample, as was later confirmed spectroscopically by Koulouridis et al. (2006).

In our H i imaging study, we select a control sample that is matched on a one-to-one basis in Hubble type, and ranges from lower to approximately the same absolute magnitude as, the sample of active galaxies selected by Kuo et al. (2008). We also matched over the observed range of optical sizes and inclinations. No visual inspection of the control sample was made to see whether they are visibly disturbed, but we are aware that the selection criteria used may select against strongly disturbed galaxies not easily classified in Hubble type. Indeed, using much the same criteria to select their control sample, de Robertis et al. (1998a) find that a higher proportion of Seyfert galaxies are involved in late-stage mergers than their control sample, although a similar fraction of the control sample displays significant light asymmetries that could be evidence for recent interactions. Note that only a small fraction of the active galaxies studied by Kuo et al. (2008) are visibly disturbed in the optical, but not so strongly that they cannot be classified in Hubble type. Nevertheless, as seen below, the fraction of optically disturbed galaxies in the Seyfert sample of Kuo et al. (2008) is higher than that in our control sample. Because our control sample is randomly selected from the field, their environments should be representative (or at least not biased in any peculiar way against those) of inactive galaxies with similar Hubble types, absolute magnitudes, and sizes as the Seyfert sample of Kuo et al. (2008).

In § 2 we describe how we selected our control sample of inactive galaxies, and in § 3 we describe our H i observations of these galaxies and the data reduction. In § 4 we present the results, and in § 5 we compare these results with those for the Seyfert sample studied by Kuo et al. (2008). In § 6 we provide a concise summary of our principle findings and their implications. Unless otherwise specified, we assume throughout a Hubble constant of \( H_0 = 67 \text{ km s}^{-1} \text{ Mpc}^{-1} \) and \( \Omega = 1 \) as used by Kuo et al. (2008).

2. SAMPLE SELECTION

As described more fully in Kuo et al. (2008), the parent sample of active galaxies comprises all 27 disk galaxies listed in the Véron-Cetty & Véron (1998) catalog plus another from the Véron-Cetty & Véron (2000) catalog at redshifts of 0.015 ≤ z ≤ 0.017 and with absolute B-band magnitudes of −19 < MB < −23 (for \( H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1} \), as used in that catalog) in the northern hemisphere (\( b > 0^\circ \)). Those galaxies were observed at an angular resolution of ∼60', which at their distances of 66–75 Mpc corresponds to a spatial resolution of ∼20 kpc. The latter is roughly comparable with the optical disk sizes of the active galaxies, and hence the H i observations were tailored toward the detection of structures extended on galactic scales characteristic of tidal features.

Our objective here is to conduct an equivalent H i imaging study of a comparable number of inactive galaxies matched as closely as is reasonable possible to the active galaxy sample. We selected our control sample from the CfA Redshift Survey i (Huchra et al. 1983, 1995) according to the following criteria:

1. Redshift.—To reduce the required observing time (which amounted to an integration time of 2 hr and an observing time of ∼2.5 hr per object in our active galaxy sample), we selected inactive galaxies at half the redshift range of our active galaxy sample, i.e., at 0.0075 ≤ z ≤ 0.0085 (distance of 33.4–37.8 Mpc). A total of 166 galaxies in the CfA redshift catalog met this criterion.

Individual samples selected in optical studies are located over a much broader range of redshifts, making one-to-one (or over-all) matching in redshift (range) important for avoiding difficulties when looking for an excess of projected neighboring galaxies between two samples. Here our objective is to search for large-scale H i disturbances in our target galaxies and determine whether these disturbances are produced by tidal interactions with neighboring galaxies. In such a case, matching in redshift is not necessary so long as we observe both samples at the same spatial resolution and detection threshold (see § 3), and provided that there is no significant cosmological evolution between the two redshifts. Of course, to look for interacting neighboring galaxies (but not necessarily to detect tidal features in the target galaxies), in both samples the field of view has to be sufficiently large to encompass any such galaxies.

2. Optical morphology and luminosity.—From the parent sample of 166 inactive galaxies, we matched on a one-to-one basis the Hubble type and optical B-band magnitude of each active galaxy to one or more inactive galaxies. Both the optical morphology and luminosity were taken from Leda, now renamed the Hyper-Leda database (Paturel et al. 2003). The morphology is matched to an accuracy of one Hubble subtype (e.g., for an Sa active

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1 See also http://cfa-www.harvard.edu/~huchra/zeat/
2 Available at http://leda.univ-lyon1.fr.
galaxy, we matched to S0a–Sab inactive galaxies) the inherent fuzziness in morphological classifications. Because the absolute magnitudes of the active galaxies include a poorly determined contribution from their bright nuclei, we allowed the match in absolute magnitude to be up to 1 mag larger (i.e., optical B-band luminosity up to a factor of 2.5 lower) than that of the corresponding active galaxy.

3. Optical size and inclination.—Based once again on the HyperLeda database, we also loosely matched in optical size by restricting the galaxy diameters to the range 0.8″–4.3″ (with the majority in the range ∼1.5″–2.5″) as measured at the 25 mag arcsec⁻² isophotal level in the B band. This range in angular diameters is roughly comparable with the corresponding range in physical diameters of the active galaxy sample. Because none of the active galaxies are close to face-on (i.e., inclinations close to 0°), we also restricted the inclinations of the inactive galaxies to angles ≥26° with respect to the plane of the sky.

4. Radio continuum.—To avoid the effect in our dynamic range of our maps, we discarded those galaxies that lie near bright radio continuum sources detected in the NRAS VLA Sky Survey (NVSS; Condon et al. 1998), which would appear in the field of view of our H i observations. Here we set a flux density cut at 21 cm of 1000 mJy. The detected flux densities of both the sample and its companions are on the order of 100 mJy. This cut will not cause any bias when comparing results of the Seyfert and control sample.

In this way, we selected 27 inactive galaxies that are closely matched in Hubble type and to the degree possible absolute magnitude, as well as range in size and inclination, to the sample of 28 active galaxies in Kuo et al. (2008). The basic properties of this matched control sample are listed in Table 1. Note that some of the values originally obtained from the Leda database have since been updated in the HyperLeda database; we list the latest, and presumably most reliable, values from the HyperLeda database. Our selection is entirely blind to the H i content of these galaxies.

In Figure 1 we plot the number distribution in morphological types, absolute magnitudes, optical sizes, and inclinations of both the active galaxy sample in Kuo et al. (2008) and our control sample. The number distribution in morphological types (top panel) shows no marked differences between the two samples within a precision of a Hubble subtype; a Kolmogorov-Smirnov (K-S) test applied to the two samples gives a K-S statistic $D = 0.18$ (converging to 0 for identical distributions) and probability $P = 0.74$ (1 for identical distributions). As intended, the absolute magnitudes (second panel) of the control sample are skewed toward larger values (i.e., lower luminosities) than the active sample. The distribution in optical sizes also is skewed toward somewhat smaller dimensions for the control sample, but the majority in both samples span the same range. The control sample has more moderately inclined (30°–45°) than highly inclined (75°–90°) galaxies compared to the active sample, but once again the majority in both samples span the same range. The relatively small differences seen between the distribution of physical properties in the active and control samples should not have a significant effect on the detectability of H i tidal features in the two samples; as shown by Kuo et al. (2008), the vast majority of the active

### TABLE 1

| Name       | R.A. (J2000.0) | Decl. (J2000.0) | z     | $M_B$ | Hubble Type | Inclination (deg) |
|------------|----------------|----------------|-------|-------|-------------|-------------------|
| IC 2461.... | 09 19 58.0     | 37 11 27.7     | 0.0075| −19.2 | Sb          | 90.0              |
| NGC 2543... | 08 12 58.0     | 36 15 16.0     | 0.0082| −20.7 | SBB         | 65.0              |
| NGC 2551... | 08 24 39.1     | 73 24 23.3     | 0.0078| −20.0 | Sa          | 50.5              |
| NGC 3094... | 10 01 26.0     | 15 46 12.0     | 0.0080| −19.8 | SBA         | 45.5              |
| NGC 3468... | 10 57 31.2     | 40 56 46.0     | 0.0252| −18.9 | S0          | 82.4              |
| NGC 3835... | 11 44 04.9     | 60 07 11.0     | 0.0082| −20.7 | Sab         | 79.8              |
| NGC 3976... | 11 55 57.6     | 06 45 03.0     | 0.0083| −20.1 | SABb        | 81.7              |
| NGC 4067... | 12 04 11.5     | 10 51 16.0     | 0.0081| −19.9 | Sb          | 47.8              |
| NGC 4128... | 12 08 32.3     | 68 46 03.0     | 0.0078| −20.1 | S0          | 90.0              |
| NGC 4256... | 12 18 43.0     | 65 53 53.0     | 0.0084| −21.4 | Sb          | 90.0              |
| NGC 4275... | 12 19 52.6     | 27 37 15.0     | 0.0077| −19.4 | Sb          | 24.2              |
| NGC 4351... | 12 24 01.5     | 12 12 18.0     | 0.0077| −20.0 | S Bab        | 44.0              |
| NGC 4384... | 12 25 12.0     | 54 30 22.0     | 0.0084| −19.7 | Sa          | 42.2              |
| NGC 4470... | 12 29 37.8     | 07 49 27.0     | 0.0078| −20.0 | Sa          | 50.0              |
| NGC 4513... | 12 32 01.5     | 66 19 57.0     | 0.0076| −19.1 | S0          | 59.0              |
| NGC 4543... | 12 35 20.2     | 06 06 54.0     | 0.0082| −18.6 | E           | 90.0              |
| NGC 4567... | 12 36 32.7     | 11 15 28.0     | 0.0076| −20.9 | Sbc         | 44.0              |
| NGC 4568... | 12 36 34.3     | 11 14 19.0     | 0.0075| −21.7 | Sbc         | 66.0              |
| NGC 4578... | 12 37 30.5     | 09 33 18.0     | 0.0076| −20.4 | S0          | 54.1              |
| NGC 4591... | 12 39 12.4     | 06 00 44.0     | 0.0081| −19.3 | Sb          | 60.3              |
| NGC 4814... | 12 55 21.9     | 58 20 38.0     | 0.0084| −20.4 | Sb          | 47.3              |
| NGC 4964... | 13 05 24.9     | 56 19 22.0     | 0.0084| −19.5 | S0–a        | 56.8              |
| NGC 5289... | 13 45 08.7     | 41 30 12.0     | 0.0084| −19.7 | SABa        | 84.9              |
| NGC 5326... | 13 50 50.7     | 39 34 30.0     | 0.0084| −20.5 | Sa          | 69.8              |
| NGC 5350... | 13 53 21.6     | 40 21 50.0     | 0.0077| −20.9 | SBBb        | 54.1              |
| NGC 5355... | 13 53 45.0     | 40 20 16.0     | 0.0078| −18.9 | S0          | 62.4              |
| NGC 5375... | 13 56 56.0     | 29 09 51.0     | 0.0080| −20.3 | S Bab        | 44.8              |

Notes.—Units of right ascension (R.A.) are hours, minutes, and seconds, and units of declination (Decl.) are degrees, arcminutes, and arcseconds. Right ascension, declination, and $z$ are from NASA/IPAC Extragalactic Database (NED). $M_B$ (absolute B-band magnitude), Hubble types, and inclination angles are from the HyperLeda database.

a The redshifts listed in the CfA redshift catalog and NED are different. Here we adopt the redshift listed in NED.
galaxies, and nearly all those classified as Seyferts, exhibit H\textsc{i} disturbances usually in the form of tidal features irrespective of their Hubble type, absolute magnitude, optical size, or inclination within the selected range.

3. OBSERVATIONS AND DATA REDUCTION

We observed the control sample with the Very Large Array\(^3\) (VLA) of the National Radio Astronomical Observatory (NRAO). Like the active galaxy sample studied by Kuo et al. (2008), we used the most compact configuration of the VLA (the D configuration). NGC 5375 had previously been adequately (for the purpose of this experiment) observed in this configuration on 1996 August 15, and so we simply retrieved the data for this galaxy from the VLA archive. The remaining galaxies were observed on 2003 February 19, 21, and 24, apart from NGC 5355, which was observed on 2004 July 14. Other relevant details of the observations, including the flux, secondary (for amplitude and phase calibration), and bandpass calibrators used for each target object, are summarized in Table 2.

The correlator was configured in the same manner described in Kuo et al. (2008), recording signals in orthogonal circular polarizations in 64 channels spanning a bandwidth of 6.25 MHz. The corresponding channel separation in velocity is \(\sim 21.2\, \text{km s}^{-1}\) (the actual velocity resolution is \(\sim 25.2\, \text{km s}^{-1}\)) and altogether spans a velocity range of \(\sim 1350\, \text{km s}^{-1}\). For the assumed cosmology, this velocity range corresponds to a redshift interval of \(\Delta z \approx 0.0045\) (distance range of \(\sim 20\, \text{Mpc}\)), compared with the redshift interval of \(\Delta z \approx 0.001\) for the control sample. The central channel is set to the systemic heliocentric velocity of the H\textsc{i} line if previously measured (usually with a single-dish telescope), or if not then at its reported optical redshift.

At 21 cm, the primary beam of the VLA is \(\sim 32'\) at full width at half-maximum, corresponding to a diameter of \(\sim 330\, \text{kpc}\) at the distance of our control sample. Our field of view for the control sample is, of course, only half the linear diameter of our field of view for the active galaxy sample, which is located at twice the distance. As described in Kuo et al. (2008), the projected separation between the Seyfert galaxies and their interacting neighboring galaxies is mostly (for \(\sim 85\%\) of the sample) \(\lesssim 100\, \text{kpc}\). Our field of view is therefore sufficiently large to encompass most of the interacting neighboring galaxies detected around the Seyfert galaxies studied by Kuo et al. (2008) even if the latter was placed at the distance of our control sample.

We targeted the same detection threshold at the same spatial resolution as Kuo et al. (2008) for their active galaxy sample. Because the control sample is a factor of 2 closer in distance, their H\textsc{i} intensity is a factor of 4 higher for the same gas mass. Everything else being equal, this would require a factor of 16 shorter integration time for our control sample, a considerable savings given that the integration time for each active galaxy in Kuo et al. (2008) was \(\sim 2\, \text{hr}\). In practice, to achieve the same spatial resolution of \(\sim 20\, \text{kpc}\) (i.e., angular resolution of \(\sim 120''\)) as in the active galaxy sample (which was imaged at an angular resolution of \(\sim 60''\)), we had to discard baselines that were more than one-third the length of the longest baselines in the active galaxy sample (i.e., using baseline up to only 1.5 k\,\lambda). Because there are more shorter than longer baselines, the actual integration time per object in our control sample was therefore \(\sim 12\, \text{minutes}\) (still a considerable savings in time over \(2\, \text{hr}\)) and the observing time per object was \(\sim 20\, \text{minutes}\) (compared with \(\sim 2.5\, \text{hr}\) for the active galaxy sample). In this way, we achieved an r.m.s flux density of \(\sim 1.8\, \text{mJy beam}^{-1}\) in one channel, corresponding to a 5 \(\sigma\) detection threshold in H\textsc{i} gas column density of \(\sim 3 \times 10^{19}\, \text{cm}^{-2}\) per synthesized beam of diameter \(\sim 120''\) (20 kpc) in a given channel with a velocity width \(\sim 25.2\, \text{km s}^{-1}\). This is the same detection threshold as reached by Kuo et al. (2008) in their active galaxy sample.

Like Kuo et al. (2008), we performed all the data reduction in the standard manner using the NRAO AIPS package. Unlike for the active galaxy sample, we found no radio frequency interference (RFI) in the data for our control sample, presumably because their redshifted H\textsc{i} lines lie closer to the protected band at 21 cm. Following bandpass calibration, as well as time-dependent amplitude and phase calibration, we subtracted the continuum emission from the visibility data by interpolating between line-free channels (determined through trial and error) on either side of the H\textsc{i} line. For NGC 4256, where there is a relatively strong continuum source in the field, we first subtracted the continuum emission of that source in the visibility plane. Finally, we made maps of each channel and corrected for the primary beam response of the antennas. We also combined the channel maps (before primary

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\(^3\) The VLA is a facility of the National Radio Astronomy Observatory, which is operated by the Associated Universities, Inc., under a cooperative agreement with the National Science Foundation (NSF).
beam correction) to make maps in total intensity (zeroth moment) and intensity-weighted mean velocity (first moment), where we tried several different combinations of spectral smoothing and minimum signal cutoff level in each channel so as to suppress the noise and bring out faint diffuse features.

4. RESULTS

We detected 21 of the 27 galaxies in our control sample. Two of the six galaxies not detected, NGC 4128 and NGC 4543, have not (to the best of our knowledge) been previously observed in H I. The reported upper limits in the integrated H I intensities for NGC 4578 (Huchtmeier & Richter 1989) and NGC 5326 (Theureau et al. 1998) are below that attained in our observations. NGC 3468 has a reported integrated H I intensity of 1.40 Jy km s\(^{-1}\) (with no reported uncertainty) in Huchtmeier & Richter (1989) and should therefore have been detected in our observation. On checking the original source of the detection in Giovannelli & Haynes (1981), we found that the actual galaxy detected was UGC 3468 and not NGC 3468 as reported in Huchtmeier & Richter (1989). NGC 5355 has a reported integrated H I intensity of 14.6 ± 1.8 Jy km s\(^{-1}\) in Huchtmeier & Richter (1989) and should therefore have been detected in our observation. On checking the original source of the detection, Richter & Huchtmeier (1991) mentioned that the 8.8′ beam of the Effelsburg telescope used for this observation would include also NGC 5353 and NGC 5354. We note that this beam also includes NGC 5350, which is one of the galaxies in our control sample. We detected NGC 5350 at a much higher integrated H I intensity than that reported by Richter & Huchtmeier (1991) for NGC 5355, suggesting that the actual H I detection was of NGC 5350.

The 21 galaxies that we detected in H I comprise our ensemble control sample from which we draw statistical results. For comparison, there are 23 active galaxies in the ensemble sample of Kuo et al. (2008), of which 18 are classified as Seyfert galaxies. The H I maps of the ensemble control sample are shown in Figures 2–26, and their H I properties are summarized in Table 3. We have overlaid each integrated H I intensity (zeroth moment) map on an optical (either the red or blue filters) image from the Second Digitized Sky Survey (DSS2). This database provides a relatively uniform set of optical images to search for any disturbances in optical starlight.

We also detected in H I a number of galaxies in the same field of view as our target galaxies. Those galaxies lying within the primary beam (i.e., within a radius of ~15′ about phase center) are listed in Table 4 and are referred to by their names from optical catalogs. We also list their optical redshifts where available, as well as their corrected apparent B-band magnitudes and Hubble types as listed in the HyperLeda database. The measured H I properties of these neighboring galaxies are summarized in Table 5. Apart from neighboring galaxies detected in H I, we also searched the HyperLeda database in a radius of ~15′ about each galaxy in our control sample to obtain a measure of the richness of their fields. We emphasize that this is by no means an exhaustive search.

4.1. Individual Galaxies

We present here the results for each galaxy, highlighting features of most relevance to this work. As in Kuo et al. (2008), we separate the individual galaxies in our ensemble control sample into the following three groups:
TABLE 3

\begin{tabular}{|l|c|c|c|c|c|c|c|}
\hline
Name & $\text{S}(\text{cont.})$ & $\text{S}(\text{H}$ & $v_{\text{sys}}(\text{H}$ & $M(\text{H}$ & H $\text{disturbed?)$ & H $\text{Group}$ & Optically $\text{disturbed?)$ \\
      & (mJy) & (mJy km s$^{-1}$) & (km s$^{-1}$) & (10$^5$ M$_{\odot}$) & & & \\
\hline
IC 2461 & 8.6 & 9428$\pm$2392 & 2260 & 2.53$\pm$0.64 & No & III & No \\
NGC 2543 & 36.8 & 18495$\pm$878 & 2471 & 5.93$\pm$0.28 & Yes & I & No \\
NGC 2551 & \ldots & 2868$\pm$184 & 2344 & 0.83$\pm$0.05 & Yes & II & No \\
NGC 3094 & 39.6 & 8931$\pm$575 & 2404 & 2.72$\pm$0.18 & Yes & II & No \\
NGC 3468 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
NGC 3383 & 7.2 & 3326$\pm$266 & 2466 & 1.07$\pm$0.09 & No & III & No \\
NGC 3976 & 11.0 & 4816$\pm$680 & 2498 & 15.81$\pm$0.22 & Weak & III & No \\
NGC 4067 & 5.7 & 1745$\pm$166 & 2425 & 0.55$\pm$0.05 & No & III & No \\
NGC 4128 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
NGC 4526 & 6.2 & 1672$\pm$740 & 2528 & 0.56$\pm$0.25 & No & III & No \\
NGC 4275 & 6.5 & 1698$\pm$664 & 2318 & 0.45$\pm$0.19 & No & III & No \\
NGC 4351 & \ldots & 3214$\pm$275 & 2600 & 0.91$\pm$0.08 & No & III & No \\
NGC 4384 & 17.4 & 1822$\pm$240 & 2512 & 0.61$\pm$0.08 & No & III & No \\
NGC 4470 & 17.1 & 6454$\pm$415 & 2340 & 1.87$\pm$0.12 & No & III & No \\
NGC 4513 & \ldots & 967$\pm$492 & 2270 & 0.27$\pm$0.14 & No & III & No \\
NGC 4543 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
NGC 4557/NGC 4568 & 155.6 & 20826$\pm$628 & 2268/2255 & 5.73$\pm$0.17 & No & III & Yes \\
NGC 4578 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
NGC 4594 & 10.0 & 1616$\pm$467 & 2425 & 0.51$\pm$0.15 & No & III & No \\
NGC 4814 & 17.5 & 2047$\pm$2229 & 2513 & 6.89$\pm$0.75 & No & III & No \\
NGC 4964 & 19.3 & 7184$\pm$818 & 2525 & 2.42$\pm$0.28 & No & III & No \\
NGC 5289 & \ldots & 6245.6$\pm$961.2 & 2519 & 2.19$\pm$0.32 & No & III & No \\
NGC 5326 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
NGC 5350 & 15.8 & 2716$\pm$1454 & 2303 & 7.67$\pm$0.41 & No & III & No \\
NGC 5355 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
NGC 5375 & 6.5 & 11921$\pm$770 & 2386 & 3.64$\pm$0.24 & No & III & No \\
\hline
\end{tabular}

Notes.—Neighboring galaxies in group I are those identified from H $\text{i}$ maps to be tidally interacting with their corresponding inactive galaxies, in group II are those identified as probably tidally interacting with their corresponding inactive galaxies, and in group III are those identified as possible candidates for producing the observed H $\text{i}$ disturbances in their corresponding inactive galaxies (see text). The second column lists the measured continuum at wavelengths of 21 cm.

TABLE 4

\begin{tabular}{|l|l|c|c|c|c|c|}
\hline
Control Sample & Neighboring Galaxy & R.A. & Decl. & $z$ & $M_B$ & Separation \\
 & & (J2000.0) & (J2000.0) & & (kpc) & Hubble Type \\
\hline
NGC 2543 & PGC 80408 & 08 12 58.7 & 36 11 47 & 0.0082 & $-17.2$ & 34 & Sc \\
NGC 2551 & UGC 4390 & 08 27 51.6 & 73 31 01 & 0.0072 & $-17.8$ & 145 & Scd \\
NGC 3094 & PGC 2806972 & 10 01 57.0 & 15 45 43 & \ldots & \ldots & 71 & Sm \\
 & HI 1002+158 & 10 01 37.8 & 15 45 14.0 & \ldots & \ldots & 30 & \ldots \\
NGC 5289 & NGC 5290 & 13 45 19.1 & 41 42 44 & 0.0086 & $-20.6$ & 130 & Sbc \\
NGC 5375 & MAPS-NGP O-325-1536477 & 13 57 29.7 & 29 03 32 & 0.0075 & \ldots & 95 & \ldots \\
\hline
\end{tabular}

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Coordinates and optical redshifts are from the NED database where available, otherwise from the HyperLeda database. $M_B$ and Hubble types are from the HyperLeda database.

TABLE 5

\begin{tabular}{|l|l|c|c|c|c|c|}
\hline
Control Sample & Neighboring Galaxy & Continuum Flux & $\text{S}(\text{H}$ & $v_{\text{sys}}(\text{H}$ & $M(\text{H}$ & H $\text{disturbed?)$ & Group \\
 & & (mJy) & (mJy km s$^{-1}$) & (km s$^{-1}$) & (10$^5$ M$_{\odot}$) & & \\
\hline
NGC 2543 & PGC 80408 & 22.2 & \ldots & \ldots & \ldots & Yes & I \\
NGC 2551 & UGC 4390 & \ldots & 9216.4$\pm$579.0 & 2169 & 26.72$\pm$1.63 & No & II \\
NGC 2551 & PGC 2755603 & \ldots & 156.33$\pm$87.33 & \ldots & 0.45$\pm$0.25 & No? & III \\
 & HI 1002+158 & \ldots & 324.81$\pm$144.13 & \ldots & 0.99$\pm$0.43 & No? & III \\
NGC 5289 & NGC 5290 & 23.5 & 6593.3$\pm$865.59 & \ldots & 23.15$\pm$2.91 & No & III \\
NGC 5375 & MAPS-NGP O-325-1536477 & \ldots & $\geq$229.45 & \ldots & $\geq$0.6 & No & III \\
\hline
\end{tabular}

Notes.—H $\text{i}$ gas properties of other galaxies in control sample field.
1. Those that clearly show H\textsc{i} tidal features tracing interactions with neighboring galaxies. These features are in the form of tidal bridges that connect the two interacting galaxies, or an extension from one or both galaxies in the direction of the other (i.e., an incomplete tidal bridge). In addition, features in the form of tidal tails comprising a protrusion or curved extension from one galaxy on the side away from the other interacting galaxy may be seen. Only 1 of the 21 galaxies in our ensemble control sample of inactive galaxies falls into this group. By comparison, 13 of the 23 galaxies in the ensemble sample of active galaxies, including 12 of the 18 classified as Seyferts, fall into this group.

2. Those that clearly show both spatial and kinematic disturbances in H\textsc{i}, but which cannot be directly linked to interactions with neighboring galaxies if any. These disturbances are in general less prominent than the tidal features observed in the first group. Only 2 of the 21 galaxies in our ensemble control sample of inactive galaxies fall into this group. Four of the 23 galaxies in the ensemble sample of active galaxies, including 3 of the 18 classified as Seyferts, fall into this group.

3. Those that show marginal or no detectable H\textsc{i} disturbances. Eighteen of the 21 galaxies in our ensemble control sample of inactive galaxies fall into this group. Only one exhibits weak H\textsc{i} disturbances; the remaining 17 exhibit no discernible H\textsc{i} disturbances. By comparison, only 6 of the 23 galaxies in the ensemble sample of active galaxies, including only 3 (2 of which exhibit weak H\textsc{i} disturbances) of the 18 classified as Seyferts, fall into this group.

Because the vast majority of the galaxies in our control sample exhibit no detectable H\textsc{i} disturbances at an angular resolution of \(~120''\) (\(~20\) kpc), for these undisturbed galaxies we show only H\textsc{i} maps at the full angular resolution attained in our observations of \(~60''\) (\(~10\) kpc). The maps at \(~120''\) angular resolution contain no extra information. For the disturbed galaxies, moment maps are shown at angular resolutions of both \(~120''\) and \(~60''\) for the reader to compare, and H\textsc{i} channel maps at an angular resolution of \(~120''\) only. The H\textsc{i} channel maps of the undisturbed galaxies are available in Figure 2. At an angular resolution of \(~60''\), the corresponding 5\sigma detection threshold in H\textsc{i} gas column density is \(~7 \times 10^{19} \text{ cm}^{-2}\) per synthesized beam in a given channel with a velocity width \(\sim 25.2 \text{ km s}^{-1}\), which is higher than the Seyfert sample. Because the Seyfert sample is twice farther away from us compared with the control sample, the detection limit in terms of the H\textsc{i} mass of the control sample (\(~6 \times 10^{6} \text{ M}_\odot\)) is lower than that of the Seyfert sample (\(~7 \times 10^{6} \text{ M}_\odot\)).

4.1.1. Group I: H\textsc{i} Tidal Features Tracing Interactions with Neighboring Galaxies

At a spatial resolution of \(~20\) kpc only one of our ensemble sample of inactive galaxies exhibits tentative H\textsc{i} disturbances, which only in the map at a spatial resolution of 10 kpc can be clearly seen to trace to tidal interactions with neighboring galaxies. Nevertheless, we generously place this sole example of its kind in group I. When categorizing the ensemble sample of active galaxies in Kuo et al. (2008), we took a more conservative approach.

4.1.1.1. NGC 2543

NGC 2543 is a barred Sb galaxy (all Hubble types from the HyperLeda database, just as for the active galaxies in our companion paper). It appears somewhat asymmetric in the optical, although not obviously disturbed. A relatively dim galaxy at a comparable optical redshift, PGC 80408, lies \(~3.4'\) (\(~36\) kpc) south of NGC 2543.

Our H\textsc{i} image at a spatial resolution of \(\sim 20\) kpc (Fig. 3) reveals that NGC 2543 shares a common envelope with PGC 80408. An examination of the channel maps at this spatial resolution (Fig. 4) reveals tentative evidence for a tidal bridge (which, if real, is at best marginally spatially resolved) connecting the two galaxies. Our H\textsc{i} image at a spatial resolution of \(\sim 10\) kpc (also shown in Fig. 3) clearly reveals that the connection between the two galaxies is indeed a tidal bridge. In addition, the H\textsc{i} disk of NGC 2543 is clearly disturbed on its southwestern side, which on this side extends much further than on the northeastern side and curls in a direction toward its interacting neighbor PGC 80408.

4.1.2. Group II: H\textsc{i} Disturbances Likely Produced by Interactions

Two of the galaxies in our ensemble control sample exhibit spatial and kinematic disturbances in H\textsc{i}, but unlike the situation in group I, the observed perturbations cannot be immediately linked to interactions with neighboring galaxies.

4.1.2.1. NGC 2551

NGC 2551 is an Sa galaxy. A dimmer galaxy at a comparable optical redshift, UGC 4390, lies \(~14.4'\) (\(~146\) kpc) to the northeast of NGC 2551. Neither galaxy appears to be visibly disturbed in the optical.

We detected both NGC 2551 and UGC 4390 in H\textsc{i}, as well as the relatively faint galaxy PGC 2755603, which has no previously reported optical redshift (Figs. 5 and 6). At a spatial resolution of \(\sim 20\) kpc (Fig. 6), the H\textsc{i} disk of NGC 2551 appears to be disturbed, with this disturbance especially prominent in the first-moment map (kinematics). The observed disturbance in the H\textsc{i} disk is even more prominent at an angular resolution of \(\sim 10\) kpc (Fig. 5), but not easily apparent in the channel maps (Fig. 7). By comparison, UGC 4390 does not appear to be disturbed in H\textsc{i} at either spatial resolution, although it is possible that the H\textsc{i} kinematic axis is not aligned with the optical major axis (the optical major axis is poorly defined in the outer regions of this galaxy). PGC 2755603 was not spatially resolved in H\textsc{i}. It is not clear whether the observed disturbance in NGC 2551 was caused by tidal interactions with (one of) these or other galaxies.

4.1.2.2. NGC 3094

NGC 3094 is a barred Sa galaxy that does not appear to be obviously disturbed in the optical. In H\textsc{i} (Fig. 8), we detected NGC 3094 and also PGC 2806972, a relatively faint galaxy that lies \(~7.5'\) (\(~78\) kpc) to the east of NGC 3094. PGC 2806972 has no previously reported optical redshift. NGC 3094 exhibits an H\textsc{i} protrusion on the southeastern side that is kinematically discontinuous from its H\textsc{i} disk. A close examination of the channel maps (Fig. 9) reveals that this protrusion is physically linked to NGC 3904. These channel maps also reveal prominent north-south extensions over a narrow velocity range not seen in the moment maps; these extensions are orthogonal to the H\textsc{i} kinematic axis of the galaxy. There are no cataloged galaxies at the location of this protrusion, nor any optical counterpart visible in the DSS2 image. It is possible that this protrusion is an incomplete tidal bridge caused by interactions with PGC 2806972.

4.1.3. Group III: Weak or no H\textsc{i} Disturbances

Eighteen of the 21 galaxies fall into this group, accounting for the vast majority of the galaxies in our ensemble control sample. Of these 18, 17 do not show any evidence whatsoever for disturbances in H\textsc{i}. Only NGC 3976, which as we explain below...
Fig. 2a. I2461

Fig. 2.—H i channel maps of the control sample with spatial resolution the same as the Seyfert sample. Contour levels are plotted at \((-3, 3, 6, 9, 12, 15) \times 0.18\) mJy beam\(^{-1}\) (1 \(\sigma\)), which corresponds to an H i column density of \(2.0 \times 10^{16}\) cm\(^{-2}\). The plus sign marks the position of the galaxy listed in the label for each panel. [See the electronic edition of the Journal for additional panels of this figure.]
Fig. 3.—Top: Optical image of NGC 2543 (control sample) from the DSS2. Middle: Contours of integrated H I intensity (zeroth moment) overlaid on the DSS2 image (left) and map of intensity-weighted H I mean velocity (first moment) with full resolution (right). Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map with the same spatial resolution as the Seyfert sample (right). In the zeroth-moment maps with full resolution, contours are plotted at (3, 20, 40, 60, 80) × 20.0 mJy beam$^{-1}$ km s$^{-1}$ (1.0 × 10$^{20}$ cm$^{-2}$). In the zeroth-moment maps with the same spatial resolution as the Seyfert sample, contours are plotted at (3, 20, 40, 60, 80) × 28.3 mJy beam$^{-1}$ km s$^{-1}$ (3.2 × 10$^{18}$ cm$^{-2}$). In the first-moment map, heliocentric velocities are indicated by the scale wedge (in km s$^{-1}$), and contours plotted at intervals of 25 km s$^{-1}$. The ellipse at the lower left corner of the bottom panels is the half-power width of the synthesized beam and has a size of 58$''$ × 53$''$ (full resolution) and 126$''$ × 113$''$ (the same spatial resolution as the Seyfert sample). [See the electronic edition of the Journal for a color version of this figure.]
Fig. 4.—H i channel maps of NGC 2543 with spatial resolution the same as the Seyfert sample. Contour levels are plotted at $(-3, 3, 6, 9, 12, 15, 18) \times 0.18 \text{ mJy beam}^{-1} (1 \sigma)$, which corresponds to an H i column density of $2.0 \times 10^{20} \text{ cm}^{-2}$. The central heliocentric velocity is shown for each channel. The plus sign marks the position of NGC 2543. The synthesized beam is shown by the ellipse at the lower left corner of the top left panel.
Fig. 5.—Top: Optical images of NGC 2551 (control sample; left) and UGC 4390 from DSS2 (right). Middle: Contours of zeroth moment overlaid on the DSS2 images. Bottom: First-moment maps. In the zeroth-moment map, contours are plotted at (3, 10, 20, 30, 40) × 24.0 mJy beam⁻¹ km s⁻¹ (9.8 × 10¹⁸ cm⁻²) (NGC 2551) and (3, 6, 9, 12, 15, 18) × 24.0 mJy beam⁻¹ km s⁻¹ (9.8 × 10¹⁸ cm⁻²) (UGC 4390). The half-power width of the synthesized beam has a size of 72'' × 55''. [See the electronic edition of the Journal for a color version of this figure.]
Fig. 6.—Top: Contours of zeroth moment of NGC 2551 and UGC 4390 overlaid on the DSS2 image (left) and first-moment map with larger field (right). Middle: Contours of zeroth moment with the same spatial resolution as the Seyfert sample overlaid on the DSS2 images. Bottom: First-moment maps with the same spatial resolution as the Seyfert sample. In the zeroth-moment maps, contours are plotted at $3, 20, 40, 60, 80 \times 24.0$ mJy beam$^{-1}$ km s$^{-1}$ (9.8 $\times$ 10$^{18}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of $136'' \times 105''$. [See the electronic edition of the Journal for a color version of this figure.]
has recently been classified as an active galaxy, shows evidence for weak disturbances.

4.1.3.1. NGC 3976

NGC 3976 is a barred Sb galaxy. It is clearly disturbed in the optical (Fig. 10), exhibiting asymmetric extensions on the northeastern and southwestern sides of the disk. Although NGC 3976 is not classified as an active galaxy by Véron-Cetty & Véron (1998), the source used to select the active galaxy sample, it is classified as a Seyfert 2 with \( \text{MB} = C0 \). Thus, if NGC 3976 was placed at the same range of redshifts as the active galaxy sample, it would have been selected as part of that sample. For internal consistency, however, we retain NGC 3976 in our control sample. If included in the active galaxy sample, this would make the conclusions reached in our study only stronger. A relatively faint galaxy at a comparable optical redshift, PGC 37490, lies \( \text{0.5} \) to the south of NGC 3976.

We detected NGC 3976, but not PGC 37490. At a spatial resolution of \( \text{20 kpc} \), the \( \text{H} \) \( \text{i} \) disk of NGC 3976 appears to be asymmetric (Fig. 10). The \( \text{H} \) \( \text{i} \) gas extends farther out on the northeastern side compared to the southwestern side, giving the disk a lopsided appearance in \( \text{H} \) \( \text{i} \). In addition, the \( \text{H} \) \( \text{i} \) kinematic axis appears to lie at a different position angle compared with the major axis of the optical disk. At a spatial resolution of \( \text{10 kpc} \) (also shown in Fig. 10), this asymmetric appearance appears to be caused in part (but perhaps not wholly) by the larger \( \text{H} \) \( \text{i} \) extension of the northeastern compared with the southwestern spiral arm.

4.1.3.2. IC 2461

IC 2461 is an edge-on Sb galaxy that does not appear to be visibly disturbed in the optical. There are no cataloged galaxies at a comparable optical redshift within \( \text{15} \) of the galaxy. At a spatial resolution of \( \text{20 kpc} \), the \( \text{H} \) \( \text{i} \) disk of IC 2461 appears to be symmetric both spatially and kinematically with no evidence for perturbations. At a spatial resolution of \( \text{10 kpc} \) (Fig. 11), the \( \text{H} \) \( \text{i} \) major and kinematic axes appear to exhibit a counterclockwise twist on the northeastern side of the disk, perhaps indicative of a warp.

4.1.3.3. NGC 3835

NGC 3835 is an Sab galaxy that is not visibly disturbed in the optical. There are no cataloged galaxies at a comparable optical redshift within \( \text{15} \) of the galaxy. At a spatial resolution of \( \text{20 kpc} \), the \( \text{H} \) \( \text{i} \) disk of NGC 3835 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of \( \text{10 kpc} \) (Fig. 12), where the central inward contraction of the intensity contours in the zeroth-moment maps is probably caused by a depression in \( \text{H} \) \( \text{i} \) intensity at the center of the galaxy (as is often observed in nearby disk galaxies).
Fig. 8.—Top: Optical images of NGC 3094 (control sample) from DSS2. Middle: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map with full resolution (right). Bottom: Contours of zeroth moment (left) and first-moment map with the same spatial resolution as the Seyfert sample (right). In the zeroth-moment maps with full resolution, contours are plotted at (3, 20, 40, 60, 80) $\times$ 28.2 mJy beam$^{-1}$ km s$^{-1}$ (1.5 $\times$ 10$^{19}$ cm$^{-2}$). In the zeroth-moment maps with the same spatial resolution as the Seyfert sample, contours are plotted at (3, 20, 40, 60, 80) $\times$ 71.7 mJy beam$^{-1}$ km s$^{-1}$ (8.5 $\times$ 10$^{18}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of 59$''$ $\times$ 52$''$ (full resolution) and 123$''$ $\times$ 111$''$ (the same spatial resolution as the Seyfert sample). [See the electronic edition of the Journal for a color version of this figure.]
4.1.3.4. NGC 4067

NGC 4067 is an Sb galaxy that is not visibly disturbed in the optical. There are no cataloged galaxies at a comparable optical redshift within 15′ of the galaxy.

At a spatial resolution of ~20 kpc, the H_i disk of NGC 4067 appears to be symmetric both spatially and kinematically with no evidence for perturbations. At a spatial resolution of ~10 kpc (Fig. 13), the H_i disk appears to be more prominent or extended on the southwestern side compared with the northeastern side. Other than this small asymmetry, the H_i disk does not exhibit any spatial or kinematic disturbances. Once again, the central inward contraction of the intensity contours in the zeroth-moment maps is probably caused by a depression in H_i intensity at the center of the galaxy.

4.1.3.5. NGC 4256

NGC 4256 is an edge-on Sb galaxy that is not visibly disturbed in the optical. There are five relatively faint cataloged galaxies at a comparable optical redshift within 15′ of the galaxy.

The H_i gas flux of NGC 4256 is the lowest among all of the galaxies in our ensemble control sample, and hence the corresponding signal-to-noise ratio of the H_i map for this galaxy is the poorest. At a spatial resolution of ~20 kpc, the H_i disk of NGC 4256 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc (Fig. 14).

4.1.3.6. NGC 4275

NGC 4275 is an Sb galaxy that has the smallest inclination among all of the galaxies in our ensemble control sample. There are no cataloged galaxies at a comparable optical redshift within 15′ of the galaxy.

At a spatial resolution of ~20 kpc, the H_i disk of NGC 4275 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc (Fig. 15).

4.1.3.7. NGC 4351

NGC 4351 is a barred Sab-type galaxy that appears to be disturbed in the sense that it is lopsided in the optical, being more extended on the western than eastern side of the galaxy. There

The H_i gas flux of NGC 4256 is the lowest among all of the galaxies in our ensemble control sample, and hence the corresponding signal-to-noise ratio of the H_i map for this galaxy is the poorest. At a spatial resolution of ~20 kpc, the H_i disk of NGC 4256 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc (Fig. 14).

4.1.3.6. NGC 4275

NGC 4275 is an Sb galaxy that has the smallest inclination among all of the galaxies in our ensemble control sample. There are no cataloged galaxies at a comparable optical redshift within 15′ of the galaxy.

At a spatial resolution of ~20 kpc, the H_i disk of NGC 4275 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc (Fig. 15).

4.1.3.7. NGC 4351

NGC 4351 is a barred Sab-type galaxy that appears to be disturbed in the sense that it is lopsided in the optical, being more extended on the western than eastern side of the galaxy. There
Fig. 10.—Top: Optical images of NGC 3976 (control sample) from the DSS2. Middle: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map with full resolution (right). Bottom: Contours of zeroth moment (left) and first-moment map with the same spatial resolution as the Seyfert sample (right). In the zeroth-moment maps with full resolution, contours are plotted at (3, 20, 40, 80) $\times$ 28.2 mJy beam$^{-1}$ km s$^{-1}$ ($1.1 \times 10^{19}$ cm$^{-2}$). In the zeroth-moment maps with the same spatial resolution as the Seyfert sample, contours are plotted at (3, 20, 40, 80) $\times$ 71.2 mJy beam$^{-1}$ km s$^{-1}$ ($8.1 \times 10^{18}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of 68$''$ × 62$''$ (full resolution) and 120$''$ × 118$''$ (the same spatial resolution as the Seyfert sample). [See the electronic edition of the Journal for a color version of this figure.]
are no cataloged galaxies at a comparable optical redshift within 15' of the galaxy.

At a spatial resolution of ~20 kpc, the H i disk of NGC 4351 appears to be symmetric both spatially and kinematically with no evidence for perturbations. At a spatial resolution of ~10 kpc (Fig. 16), the H i disk is asymmetric in that it is more prominent or extended on the western side, just like in the optical.

4.1.3.8. NGC 4384

NGC 4384 is an Sa galaxy that is not visibly disturbed in the optical. There is a relatively faint galaxy, PGC 2478952, with a comparable optical redshift at ~14.9' (~162 kpc) from NGC 4384. That galaxy was not detected in H i.

At a spatial resolution of ~20 kpc, the H i disk of NGC 4384 appears to be symmetric both spatially and kinematically with no evidence for perturbations. At a spatial resolution of ~10 kpc (Fig. 17), the H i disk may be somewhat asymmetric in that the eastern side appears to be more prominent or extended.

4.1.3.9. NGC 4470

NGC 4470 is an Sa-type galaxy that is not visibly disturbed in the optical. The galaxy that is closest in optical redshift and that lies within 15' of NGC 4470 differs in systemic velocity by ~900 km s^-1 and lies outside the velocity coverage of our H i observation.

At a spatial resolution of ~20 kpc, the H i disk of NGC 4470 appears to be symmetric both spatially and kinematically with no evidence for perturbations. At a spatial resolution of ~10 kpc, the H i disk may show weak asymmetries (Fig. 18).

4.1.3.10. NGC 4513

NGC 4513 is an S0 galaxy that is not visibly disturbed in the optical. There are no cataloged galaxies at a comparable optical redshift within 15' of the galaxy.

At a spatial resolution of ~20 kpc, the H i disk of NGC 4513 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc.
Fig. 12.—*Top:* Optical image of NGC 3835 (control sample) from the DSS2. *Bottom:* Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at $3, 10, 20, 30, 40 \times 31.2$ mJy beam$^{-1}$ km s$^{-1}$ (1.6 $\times$ 10$^{19}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of 63$''$ $\times$ 51$''$. [See the electronic edition of the Journal for a color version of this figure.]
Fig. 13.—Top: Optical image of NGC 4067 (control sample) from the DSS2. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at (3, 10, 20, 30, 40) × 31.2 mJy beam$^{-1}$ km s$^{-1}$ (1.5 × 10$^{19}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of 62″ × 54″. [See the electronic edition of the Journal for a color version of this figure.]
Fig. 14.—Top: Optical image of NGC 4256 (control sample) from the DSS2. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at (3, 6, 9, 12, 15) × 38.0 mJy beam⁻¹ km s⁻¹ (1.8 × 10³⁹ cm⁻²). The half-power width of the synthesized beam has a size of 67'' × 51''. [See the electronic edition of the Journal for a color version of this figure.]
Fig. 15.—Top: Optical image of NGC 4275 (control sample) from the DSS2. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at (3, 10, 20, 30, 40) × 23.2 mJy beam$^{-1}$ km s$^{-1}$ (1.1 × 10$^{19}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of 63″ × 55″. [See the electronic edition of the Journal for a color version of this figure.]
Fig. 16.—Top: Optical image of NGC 4351 (control sample) from the DSS2. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at (3, 10, 20, 30, 40) × 20.8 mJy beam$^{-1}$ km s$^{-1}$ (1.1 × 10$^{19}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of 59$''$ × 54$''$. [See the electronic edition of the Journal for a color version of this figure.]
Fig. 17.—Top: Optical image of NGC 4384 (control sample) from the DSS2. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at (3, 10, 20, 30, 40) × 18.0 mJy beam\(^{-1}\) km s\(^{-1}\) (7.8 × 10\(^{16}\) cm\(^{-2}\)). The half-power width of the synthesized beam has a size of 66\(^\prime\) × 56\(^\prime\). [See the electronic edition of the Journal for a color version of this figure.]
Fig. 18.—Top: Optical image of NGC 4470 (control sample) from the DSS2. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at (3, 20, 40, 60, 80) × 17.0 mJy beam$^{-1}$ km s$^{-1}$ (8.4 × 10$^{18}$ cm$^{-2}$). The half-power width of the synthesized beam has a size of 62$''$ × 53$''$. [See the electronic edition of the Journal for a color version of this figure.]
resolution of \( \sim 10 \) kpc (Fig. 19). This galaxy has the third lowest \( \text{H} \text{i} \) flux among our ensemble control sample, with the resulting low signal-to-noise ratio making the presumed central depression in \( \text{H} \text{i} \) gas particularly prominent.

4.1.3.11. NGC 4567 and NGC 4568

Both NGC 4567 and NGC 4568 are Sbc galaxies that form an optically overlapping pair with comparable optical redshifts. In this way, NGC 4567/NGC 4568 resemble UGC 3995/UGC 3995A in the active galaxy sample. Both NGC 4567 and NGC 4568 are included in our control sample. There are no other cataloged galaxies at a comparable optical redshift within \( 15' \) of the galaxy.

Despite their apparent proximity and similar redshifts, as in the case of UGC 3995/UGC 3995A we detect no \( \text{H} \text{i} \) disturbances at a spatial resolution of \( \sim 20 \) kpc, nor at a spatial resolution of \( \sim 10 \) kpc (Fig. 20), in either NGC 4567 or NGC 4568. Indeed, in a much deeper \( \text{H} \text{i} \) observation at an angular resolution of \( \sim 20'' \), Iono et al. (2005) detected no extended tidal features in this pair of galaxies.

4.1.3.12. NGC 4591

NGC 4591 is an Sb galaxy that is not visibly disturbed in the optical. There are no cataloged galaxies at a comparable optical redshift within \( 15' \) of the galaxy.

At a spatial resolution of \( \sim 20 \) kpc, the \( \text{H} \text{i} \) disk of NGC 4591 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of \( \sim 10 \) kpc (Fig. 21).

4.1.3.13. NGC 4814

NGC 4814 is an Sb galaxy that is not visibly disturbed in the optical. There is a relatively faint galaxy, SDSS J125426.85+582348.9, with a comparable optical redshift at \( \sim 7.9' \) (\( \sim 86 \) kpc) from NGC 4384. That galaxy was not detected in \( \text{H} \text{i} \).

At a spatial resolution of \( \sim 20 \) kpc, the \( \text{H} \text{i} \) disk of NGC 4814 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of \( \sim 10 \) kpc (Fig. 22).
4.1.3.14. NGC 4964

NGC 4964 is an S0-a galaxy that is not visibly disturbed in the optical. There are no cataloged galaxies at a comparable optical redshift within 15' of the galaxy.

At a spatial resolution of ~20 kpc, the H i disk of NGC 4964 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc (Fig. 23).

4.1.3.15. NGC 5289

NGC 5289 is a nearly edge-on barred Sa galaxy that is not visibly disturbed in the optical. There are six mostly relatively faint cataloged galaxies at a comparable optical redshift within 15' of NGC 5289. Their separations range from 5.3' (~58 kpc) to 12.7' (~138 kpc) from NGC 5289. Only one of these neighboring galaxies, NGC 5290, lying farthest away from and brighter in the optical than NGC 5289, was detected in H i.

At a spatial resolution of ~20 kpc, the H i disk of NGC 5289 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc (Fig. 24).

4.1.3.16. NGC 5350

NGC 5350 is a barred Sbc galaxy that appears to be somewhat asymmetric although not obviously disturbed in the optical. There are seven cataloged galaxies at a comparable optical redshift within 15' of NGC 5350, two of which are comparably bright and the remainder relatively faint. None of these neighboring galaxies were detected in H i.

At a spatial resolution of ~20 kpc, the H i disk of NGC 5350 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of ~10 kpc (Fig. 25).

4.1.3.17. NGC 5375

NGC 5375 is a barred Sab galaxy that is not visibly disturbed in the optical. There is a relatively faint galaxy, PGC 49623, with a comparable optical redshift at ~4.6' (~47 kpc) from NGC 5375. That galaxy was not detected in H i. Instead, we detected the...
galaxy MAPS-NGP O-325-1536477 (as cataloged in the NASA Extragalactic Database), which has no previously reported optical redshift and is 9.4\(\pm\) 0.8 (131 kpc) to the southeast of NGC 5375. At a spatial resolution of \(\sim\)20 kpc, the H\(_i\) disk of NGC 5375 appears to be symmetric both spatially and kinematically with no evidence for perturbations. The same also is true at a spatial resolution of \(\sim\)10 kpc (Fig. 26).

### 4.2. Other Galaxies in Target Fields

Apart from the optically overlapping pair NGC 4567/NGC 4568, we detected only six other galaxies in H\(_i\) within the primary beam of our target fields. None of these galaxies exhibit H\(_i\) disturbances at either 20 or 10 kpc spatial resolution. The H\(_i\) maps of these galaxies are shown together with the maps for the control sample galaxies.

### 4.3. Ensemble Statistics

We now make statistical inferences from the results based on our ensemble control sample of 21 galaxies that we mapped in H\(_i\). Only 4 of the 21 (\(\sim\)19\%) galaxies in the control sample exhibit detectable disturbances at a spatial resolution of \(\sim\)20 kpc. By contrast, 17 of the 21 (\(\sim\)81\%) galaxies exhibit no H\(_i\) disturbances whatsoever at this spatial resolution. One of these disturbed galaxies (NGC 3976) has since been found to be a Seyfert 2 galaxy, and so only 3 of the 20 (15\%) inactive galaxies are actually disturbed in H\(_i\), whereas 17 of 20 (\(\sim\)85\%) show no H\(_i\) disturbances. The H\(_i\) disturbances can be directly traced to tidal interactions with neighboring galaxies. In the remaining two cases with H\(_i\) disturbances, the observed disturbances are likely to be produced by tidal interactions with neighboring galaxies also detected in H\(_i\). By comparison, 17 of the 18 (\(\sim\)94\%) Seyfert galaxies in the ensemble sample of Kuo et al. (2008) exhibit H\(_i\) disturbances, 12 (\(\sim\)67\%) of which are interacting with neighboring galaxies (group I), another 3 (\(\sim\)17\%) probably interacting with neighboring galaxies (group II), and the remaining 2 (\(\sim\)12\%) weakly disturbed (group III).

Only 2 of the 21 (\(\sim\)10\%) galaxies in the control sample are visibly disturbed in optical DSS2 images. Leaving aside NGC 3976,
since found to be a Seyfert 2 galaxy, only 1 of 20 (\(\sim 5\%\)) inactive galaxies are optically disturbed. By comparison, 6 of the 23 (\(\sim 26\%\)) galaxies in the ensemble sample of active galaxies studied by Kuo et al. (2008) are visibly disturbed in optical DSS2 images, including 5 of the 18 galaxies (\(\sim 28\%\)) classified as Seyferts. As pointed out in § 1, the selection criteria used may select against (strongly) optically disturbed galaxies in the control sample. Nonetheless, the relatively small difference in the frequency of optical disturbances between the Seyfert and control samples (\(\sim 28\%\) vs. \(\sim 5\%\)) pales in comparison to the dramatic difference in the frequency of H\(_i\) disturbances between these two samples (\(\sim 94\%\) vs. \(\sim 15\%\)).

In case of any severe selection bias against optically disturbed galaxies in our control sample, here we compile statistics for just the optically undisturbed galaxies in the control sample. Of the 13 such Seyfert galaxies, 12 (\(\sim 92\%\)) exhibit H\(_i\) disturbances, 9 (\(\sim 69\%\)) of which are interacting with neighboring galaxies (group I), 1 (\(\sim 7\%\)) possibly interacting with a neighboring galaxy (group II), and 2 (\(\sim 15\%\)) weakly disturbed (group III). By comparison, only 3 of the 20 (\(\sim 15\%\)) optically undisturbed inactive galaxies are disturbed in H\(_i\).

5. INTERPRETATION AND DISCUSSION

5.1. Relative H\(_i\) Gas Masses

We first examine whether the dramatic difference in H\(_i\) disturbances between the active and control samples might be caused by differences in their H\(_i\) gas masses. This could happen if, for example, the same fractional H\(_i\) gas mass is displaced into tidal features of equal spatial dimensions in a given interaction. In such a case, interacting galaxies with lower H\(_i\) gas masses will exhibit dimmer tidal features, which may fall below the detection threshold in a given observation.

In Figure 27 we plot the H\(_i\) gas masses of the active and control samples. As can be seen, the active sample is distributed toward somewhat higher H\(_i\) gas masses than the control sample.
A K-S test gives a statistic $D = 0.30$ (converging to 0 for identical distributions) and probability $P = 0.23$ (1 for identical distributions). More importantly, most of the galaxies in our control sample span the same range of H\textsc{i} gas masses as the active sample for which we detect H\textsc{i} disturbances. We therefore believe that the dramatic difference in H\textsc{i} disturbances between the two samples cannot be caused by the relatively small difference in their overall distributions of H\textsc{i} gas masses. The possibility that tidal features in our control sample somehow conspire to be less spatially extended than those in the active sample is ruled out by our H\textsc{i} images of the control sample at a spatial resolution of $\sim 10$ kpc.

5.2. Incidence of Neighboring Galaxies

In Figure 28 we show the cumulative fraction of Seyfert galaxies (solid line) studied by Kuo et al. (2008) with (candidate) interacting neighboring galaxies (i.e., in groups I, II, or III), plotted as a function of their projected separations (for the few with multiple interacting neighboring galaxies, their nearest such neighbor). As explained in Kuo et al. (2008), over the range of projected separations plotted (up to 90 kpc), there are only two neighboring galaxies not identified to be (possibly) interacting with their respective (the same) Seyfert galaxy, the third of which is identified as the interacting neighbor. Thus, including all possible neighboring galaxies around Seyfert galaxies does not change this figure, at least within the range of projected separations plotted. In the same figure, we also plot the cumulative fraction of galaxies in our control sample (dashed line) with neighboring galaxies within the same range of projected separations. (Keep in mind that our observations span the same velocity interval for both samples.) Our detection threshold is relatively uniform (within $\sim 20\%$) and essentially the same for both the Seyfert and control samples at projected separations up to $\sim 90$ kpc. As can be seen, the frequency of Seyfert galaxies with neighboring galaxies is clearly much higher than that of the control sample over the range of projected separations plotted. This difference simply
Fig. 24.—Top: Optical image of NGC 5289 (control sample) and NGC 5290 from the DSS2. Middle: Contours of zeroth moment overlaid on the DSS2 image. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map with larger field (right). In the zeroth-moment maps, contours are plotted at $(3, 10, 20, 30, 40) \times 20.8 \text{ mJy beam}^{-1} \text{ km s}^{-1} \left(9.6 \times 10^{18} \text{ cm}^{-2}\right)$. The half-power width of the synthesized beam has a size of $62'' \times 56''$. [See the electronic edition of the Journal for a color version of this figure.]
reflects the prevalence of tidal interactions in the Seyfert but not control sample.

As mentioned in § 1, some optical studies find an excess of Seyfert galaxies with (projected) neighboring galaxies compared with inactive galaxies, whereas others do not. A discussion of the different methodologies used in different studies, as well as reasons for their conflicting results, is beyond the scope of this paper. Any comparison made between previous optical and our H\textsc{i} studies should keep in mind that our H\textsc{i} imaging study is not designed to address differences between the fraction of Seyfert and inactive galaxies with neighboring galaxies. (Rather than looking for any such difference, we directly determine what fraction of Seyfert and inactive galaxies show H\textsc{i} disturbances and where possible determine whether these disturbances are caused by tidal interactions with neighboring galaxies.) Both the study of Kuo et al. (2008) and that reported here can only detect relatively gas-rich galaxies, and so an H\textsc{i} census of neighboring galaxies is likely to be less complete than an optical census.

Nevertheless, to see what can be learned, we compare the results of our H\textsc{i} studies with the optical studies of Dultzin-Hacyan et al. (1999) and Koulouridis et al. (2006), who measured the fraction of galaxies in both their Seyfert and control samples with (projected) neighboring galaxies as a function of their projected separations. Both these studies employed the same Seyfert and control samples; the Seyfert sample was taken from the catalog of Lipovetsky et al. (1988), which contained most, if not all, of the then known Seyfert galaxies and the matched control sample from the CfA survey (Huchra et al. 1983).

Dultzin-Hacyan et al. (1999) searched for projected neighboring galaxies within a radius of \sim 140 kpc using the (first) Digitized Sky Survey (DSS). They found that in both their Seyfert and control samples, the fraction having projected neighboring galaxies with diameters 4–10 kpc increases as the search radius widens, reaching between 80% and 100% within a search radius of \sim 100 kpc (see Fig. 1 of Dultzin-Hacyan et al. 1999). At any given search radius, the fraction of Seyfert I and inactive galaxies

![Figure 25](image_url)

**Fig. 25.**—Top: Optical image of NGC 5350 (control sample) from the DSS2. Bottom: Contours of zeroth moment overlaid on the DSS2 image (left) and first-moment map (right). In the zeroth-moment map, contours are plotted at (3, 10, 20, 20, 40) \times 31.8 mJy beam\textsuperscript{-1} km s\textsuperscript{-1} (1.5 \times 10\textsuperscript{19} cm\textsuperscript{-2}). The half-power width of the synthesized beam has a size of 61\arcsec \times 56\arcsec. [See the electronic edition of the Journal for a color version of this figure.]
by Dultzin-Hacyan et al. (1999), Koulouridis et al. (2006) find a relatively large difference between the fraction of Seyfert 2 (but, again, not Seyfert 1) galaxies with neighboring galaxies within a velocity difference of 200 km s⁻¹ compared with inactive galaxies at the smallest measured projected separation of 7 kpc, with this difference diminishing as the search radius widens until disappearing at roughly 70 kpc (scaled to $H_0 = 67$ km s⁻¹ Mpc⁻¹).

With a maximum search radius of ~70 kpc and a limiting magnitude of $m_B \sim 15.5$ (1 mag brighter than the LMC at the distance of our sample), this study would have picked up only a small fraction of the interacting neighboring galaxies that Kuo et al. (2008) detected around their Seyfert sample. Indeed, Koulouridis et al. (2006) find that only ~10% of Seyfert 1 galaxies and ~30% of Seyfert 2 galaxies have neighboring galaxies within the range of parameters searched. Going to a lower limiting magnitude of $m_B \sim 18.5$ (corresponding to the SMC at the distance of our sample) for a subset of their sample, Koulouridis et al. (2006) find that about twice as many still of both Seyfert 1 and Seyfert 2 galaxies have neighboring galaxies within a projected separation of ~50 kpc. This fraction is comparable to what we found in our Seyfert sample (~40% at a projected separation of ~50 kpc). Unfortunately, Koulouridis et al. (2006) did not search for neighboring galaxies down to the same low limiting magnitudes around their control samples, and hence a more detailed comparison cannot be made.

5.3. Implicating Tidal Interactions in Triggering AGNs

The contrast between the prevalence of H i disturbances in the active and control samples is dramatic. In the active galaxy sample, we can only find a few galaxies that are not disturbed spatially and usually also kinematically on galactic-wide ($\gtrsim 20$ kpc) scales. In the control sample, we find the opposite result, with most exhibiting no detectable spatial or kinematic disturbances on both the same and smaller (\lesssim 10 kpc) scales.

Specifically, of the 18 galaxies in the ensemble sample of 23 active galaxies classified as Seyferts, 17 (\sim 94%) exhibit H i disturbances. In at least \sim 67% and possibly as high as \sim 94% of cases, the observed H i disturbances can be traced to tidal interactions with neighboring galaxies detected also in H i. By contrast, only 4 of the 21 (\sim 19%) galaxies in our control sample exhibit H i disturbances. Removing the one disturbed galaxy since found to be a Seyfert 2 galaxy, only 3 of the 20 (15%) are actually disturbed in H i. Only 1 of the 18 (\sim 6%) Seyfert galaxies in the ensemble active galaxy sample exhibits no detectable disturbances.

Our results agree with those of Dultzin-Hacyan et al. (1999) in two important respects. First, nearly all the Seyfert galaxies studied by Dultzin-Hacyan et al. (1999) have projected neighboring galaxies within \sim 100 kpc. Second, we both see an excess of Seyfert galaxies (our ensemble sample contains a much larger fraction of Seyfert 2 than Seyfert 1 galaxies) having (projected) neighboring galaxies at projected separations smaller than \sim 90 kpc compared with the control sample. Where we differ is in our seeing this excess becoming increasingly larger with projected separation up to 90 kpc, whereas Dultzin-Hacyan et al. (1999) find this excess to become increasingly smaller with projected separation before disappearing at \sim 100 kpc. Keep in mind, however, that our H i imaging observations cleanly pick out genuine neighboring but only gas-rich galaxies, whereas those of Dultzin-Hacyan et al. (1999) may include spurious objects.

Koulouridis et al. (2006) repeated the study of Dultzin-Hacyan et al. (1999), but now armed with redshifts from the second CfA and Southern Sky Redshift Surveys. Confirming the trends seen in their H i moment maps, they find that only 3 of the 18 galaxies in the ensemble sample show H i disturbances. This is consistent with the fact that only 3 of the 20 galaxies in the control sample show H i disturbances. Additionally, they find that only 1 of the 18 galaxies in the ensemble sample shows no detectable H i disturbances, whereas none of the 20 galaxies in the control sample shows this behavior.
disturbances whatsoever. By contrast, 17 of the 20 (85%) galaxies in our control sample exhibit no detectable H\textsc{i} disturbances. These results directly implicate tidal interactions in initiating events that lead to optically luminous Seyfert activity in a large fraction of local disk galaxies.

6. SUMMARY AND CONCLUSIONS

The central purpose of this paper is to determine whether the high incidence of tidal interactions observed in H\textsc{i} gas for a sample of Seyfert galaxies reported in the companion paper by Kuo et al. (2008) is related to their AGN activity. Our strategy was to image at the same spatial resolution (~20 kpc) and sensitivity in H\textsc{i} gas a comparably large number of inactive galaxies that were closely matched in Hubble type and to the degree possible optical luminosity, as well as range in size and inclination, to the active galaxies. We detected 21 of the 27 galaxies in our control sample, imaged at the same spatial resolution and H\textsc{i} column density threshold as the active galaxy sample. These 21 galaxies comprised our ensemble control sample from which we drew the following statistical results:

1. Only 4 of the 21 galaxies (~19%) exhibit spatial and usually also kinematic disturbances on galactic (~20 kpc) scales. One of these disturbed galaxies has since been found to be a Seyfert 2 galaxy, and so only 3 of the 20 (15%) inactive galaxies in our ensemble control sample are actually disturbed in H\textsc{i}.

2. Seventeen of the 21 galaxies (81%) show no H\textsc{i} disturbances whatsoever on galactic (~20 kpc) scales. Excluding again the one disturbed galaxy since found to be a Seyfert 2 galaxy, 17 of the 20 (85%) inactive galaxies in our ensemble control sample are not disturbed in H\textsc{i}.

By contrast, of the 18 galaxies in the ensemble sample of 23 active galaxies classified as Seyferts, 17 (~94%) exhibit H\textsc{i} disturbances. In at least ~67% and possibly as high as ~94% of cases, the observed H\textsc{i} disturbances can be traced to tidal interactions with neighboring galaxies detected also in H\textsc{i}. The dramatic contrast in the incidence of H\textsc{i} disturbances between the active and inactive galaxy samples strongly implicates tidal interactions in initiating events that lead to luminous Seyfert activity in a large fraction of local disk galaxies.

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