An H\textsc{i} Rogues Gallery

J.E. Hibbard  
*NRAO*

J.H. van Gorkom  
*Columbia University*

Michael P. Rupen  
*NRAO*

David Schiminovich  
*Caltech*

**Abstract.** We have begun a compilation of H\textsc{i} maps of peculiar galaxies kindly contributed by individual investigators, many as part of the “Gas & Galaxy Evolution” conference. In this gallery we present images of the first \(\sim 180\) objects, which includes over 400 individually cataloged galaxies. The images consist of a greyscale representation of the optical morphology and an accompanying optical image with H\textsc{i} contours superimposed. A web-based “living Gallery” is being maintained on the NRAO homepage (presently at [http://www.nrao.edu/astrores/HIrogues/](http://www.nrao.edu/astrores/HIrogues/)).

1. Introduction

Arp’s “Atlas of Peculiar Galaxies” (Arp 1966) appeared forty years after the discovery that galaxies are independent stellar systems. It was motivated by some of the questions which form central themes of this conference: How are elliptical galaxies related to spirals? How are galaxies formed, and how do they evolve? These questions are just as compelling today as they were in 1966. It is certainly true that optical compilations of the bizarre objects collected by Arp and others (notably, Vorontsov-Vel’yaminov 1959, 1977; Arp & Madore 1987; Malin & Carter 1983) and the detailed studies that they motivated have brought us an appreciation that peculiar galaxies have an importance far in excess of their statistical occurrence in galaxy catalogs, where they comprise anywhere from 3–9\% of all objects (Arp & Madore 1975; Struck 1999). Still, thirty-five years later these questions remain largely unanswered.

By the time atlases of peculiar galaxies appeared, there were several catalogs devoted to demonstrating the various forms of galaxy morphology. Most prominent among these is the Hubble Atlas. These catalogs are arranged in sequences based on the symmetry of the optical morphologies, and focus on sin-
galaxies in isolation, with asymmetric forms relegated to catch-all categories and illustrated with but a few token examples. The compendiums of peculiar galaxies, on the other hand, highlight those forms which deviate from symmetry, with the thinking that such objects are transitional forms illustrating the most spectacular phases of galactic evolution, and perhaps formation.

Optical morphology alone provides an interesting yet incomplete view of galaxies. This is particularly true when considering peculiar systems. The starlight in galaxies rarely extends beyond a few optical scale-lengths, well within the dark matter halos that are widely believed to surround galaxies. Any tracer that extends to larger radii will probe the influence of a larger fraction of the mass of galaxies and, because the dynamical time scales with radius, will sample galactic influences further in the past. The 21 cm line of neutral hydrogen forms just such a tracer. Since the early days of radio astronomy, it has been known that the neutral gas often extends much further than the optical light (Roberts & Rots 1973). Additionally, hydrogen is the raw material from which stars and therefore galaxies are ultimately formed, so if large reservoirs of it exist at the present time, we might hope to find signatures of on-going formation processes in the neutral gas. No picture of galaxy formation and evolution is complete without knowledge of how the gas is distributed at large radii.

It is somewhat surprising, then, that thirty-five years after the optical compilation of Arp, no such compilation of H\(_i\) maps exist for peculiar galaxies. This is not for lack of such observations. H\(_i\) mapping requires an extensive investment in telescope time and post-observation reduction, limiting most studies to a few to a dozen objects in any given observational program. Nonetheless, an impressive amount of data on H\(_i\) in weird galaxies and weird H\(_i\) in otherwise normal galaxies has been amassed over the years. By our count, more than 400 peculiar systems have been mapped in H\(_i\). This may be far below the number of objects typically assembled in optical catalogs, but it is enough to warrant an attempt to assemble and arrange them in some organized form.

This Gallery is intended to do just that, and we have taken the occasion of this meeting, celebrating the twentieth anniversary of the VLA, to make a first attempt at its compilation. We concentrate on H\(_i\) maps of peculiar galaxies or peculiar H\(_i\) in otherwise normal galaxies, rather than attempting to include all Hubble Types. We have further limited ourselves to very disturbed systems, by and large including only a few (or no) examples of systems with less extreme peculiarities. There are already relatively large compilations of the H\(_i\) morphology of “normal” Hubble types, many of which exhibit both minor and major peculiarities, in (mostly Dutch) theses or journal supplements (e.g. Wevers, van der Kruit & Allen 1986; Bosma 1978; Warmels 1988; Cayatte et al. 1990; van Driel & van Woerden 1991; Oosterloo 1988; Broeils 1992; Swaters 1999; Verheijen & Sancisi 2001), and the growing database of the Westerbork H\(_i\) Survey of Irregular and Spiral Galaxies (WHISP) will eventually contain more than 400 late-type galaxies (van der Hulst, van Albada & Sancisi, these proceedings, p. 451). On the other hand, no large compilation of H\(_i\) in peculiars exists anywhere. This “Rogues Gallery” is our attempt to remedy this situation.

This is a very subjective compilation, assembled because one of us noticed the H\(_i\) map of a given object somewhere and considered it interesting, or had marked the galaxy as an optically interesting object and subsequently searched
the literature or telescope archives for existing H\textsc{i} observations. This assemblage is definitely not complete, and may not even be representative of all the forms of peculiar H\textsc{i} morphologies — for that we would need an optically blind H\textsc{i} survey. But one has to start somewhere, and this is where we have decided to start.

Following the practice of Hubble, Sandage, Arp, and Madore, we have divided the Gallery into several morphological classes. These are described in detail in §3. Within each class we have attempted to arrange objects in a suggestive morphological sequence, where the principles behind those sequences are described in §3.1. The general theme is the connection of similar forms, related from a dynamical (as with the class of interacting galaxies) or a morphological viewpoint (as with the class of galaxies with warps and/or asymmetries). Sometimes there is no clear transition between objects, and the category is just a compilation of systems that fall within the broadly defined class (as with the class of galaxies with extended H\textsc{i} envelopes).

The Gallery is laid out as follows. We describe the subjective gathering of the images and the proper way to reference them in §2. In §3 we define the different classes used and explain how objects are ordered in the Gallery. The layout of the images is described in §4, while §5 describes the tables and their entries. The acknowledgements appear in §6, followed by the tables, and finally the Gallery itself. At the end of the Gallery we have collected abstracts for authors who have allowed us to reproduce images prior to their publication in the literature.

2. Sources of Images and References

A list of candidate objects for the Gallery has been continuously assembled from the literature and personal communications by JEH. Prior to this meeting, we also searched the VLA archive and the compilation of Martin (1998) for H\textsc{i} mapping observations of galaxies noted by us to be optically peculiar in some manner. As such, this is an entirely subjective assemblage and can in no way be considered complete. We do hope that it is representative (although it may well not be).

Using this list as a guide, we tried to contact the observers who made the observations in the early part of 2000 to see if they would consider donating FITS images or postscript files of the resulting H\textsc{i} maps for inclusion in the Gallery. We made another attempt to increase the number of objects in the early part of 2001. The present collection includes the results (please see §6 for acknowledgments). It amounts to 181 systems (including over 400 individually cataloged galaxies) out of our original list of ∼400; there is thus much room for improvement. Additionally, there are likely a large number of objects, either published or unpublished, that we have missed entirely. We plan on actively maintaining this Gallery on the NRAO webpage (currently stored at [http://www.nrao.edu/astrores/HIroques]), and encourage observers who notice any omissions (or wish themselves to contribute an image) to contact us.

The H\textsc{i} maps in this compilation are mainly from two major centimeter wavelength interferometers, the Very Large Array (VLA) and the Westerbork Synthesis Radio Telescope (WSRT). A few images were taken from observations...
with the Australia Telescope Compact Array (ATCA), but there are undoubt-
edly dozens of systems observed with that telescope which are not included
here. Our hope is that we can remedy this in the near future, or perhaps
that there will be a Northern and Southern Gallery maintained at NRAO and
ATNF (a list of all galaxies observed with the ATCA is presently maintained
at [http://www.atnf.csiro.au/people/bkoribal/atca_obs.html](http://www.atnf.csiro.au/people/bkoribal/atca_obs.html)). Similarly, al-
though no mapping observations from the Giant Metrewave Radio Telescope
(GMRT) are included so far, that instrument is likely to become another major
source of images in the future. It is notable that we have included only four
mapping observations made with single dish telescopes, primarily because such
maps are often unavailable in machine readable form. We can expect very inter-
esting results on the large scale gaseous distribution of local galaxies from single
dish maps from the HIPASS survey with Parkes telescope (see Koribalski, these
proceedings, p. 439) and the Green Bank Telescope in the near future.

Many of the images presented in this Gallery have appeared in the literature.
However, we are particularly and deeply grateful for those observers who have
made their data available prior to publication. To ensure that these observers
receive proper credit for this work, we have collected short abstracts under
their names at the end of the Gallery, which include brief descriptions of these
observations. If readers wish to reference these images, they should cite the
abstracts, which are also referenced in the figure captions.

3. Rogues Gallery Classifications

In this first attempt at constructing an atlas of this sort, we have arranged the
systems following the lead of Arp (1966). In particular, we define several broad
morphological classes, but make no clear breaks between the classes, and the
objects are often arranged so that the last objects of one class are similar to
the first objects of the following one. Overall, the major motivation for placing
an object on a specific page is to have it appear between systems that it most
resembles.

These classes are defined morphologically, and within each category, objects
are presented in a suggestive sequence. The order within a class is sometimes mo-
tivated by dynamical considerations, e.g., the arrangement of interacting galaxies
in a suggested evolutionary sequence. These motivations and guiding principles
are explained in the following sub-section, which also gives detailed motivations
for placing some specific objects in one sequence rather than another.

Table 1 shows the arrangement of the Gallery, along with the criteria for
ordering of objects within classes, and Table 2 lists the individual galaxies in the
order in which they appear. As mentioned above the last object of one class is
often similar to the first object of the next one. The classification of galaxies is
a very subjective task, and many systems could easily fit into several categories.
This is a work in progress and we welcome your comments.

3.1. Detailed Notes on Classifications and Ordering

The first class of objects in the Gallery is Galaxies with Extended \( \text{H}_1 \) En-
velopes, where the \( \text{H}_1 \) extent is compared to the underlying optical light rather
than to a fixed physical scale. The rest of the Gallery is dominated by interacting
systems, many of which also have very extended H\textsubscript{I} distributions. In this first class, we include objects which do not apparently owe their extended H\textsubscript{I} to an interaction\textsuperscript{1}. By this we mean that there is not an obvious partner with which the system is interacting, nor are there tell-tale signs of a prior minor or major merger event (see below), such as stellar shells and loops or multiple nuclei.

This classification includes many Blue Compact Dwarfs (BCDs), although BCDs also appear elsewhere in the Gallery. For example, UGC 00521 appears with warps, and there are several BCDs filed under Miscellaneous, which may not have been mapped with enough sensitivity to determine whether or not they have extended gas envelopes. BCDs are some of the most unevolved systems in the nearby universe, in terms of their stellar content and metallicity, and as such this Extended H\textsubscript{I} class may include examples of galaxies actually forming out of the gaseous reservoirs in which they are embedded. For this reason, we have arranged galaxies within this class based on the regularity of their H\textsubscript{I} morphology: galaxies with very irregular outer H\textsubscript{I} are at the beginning, and galaxies with disk-like H\textsubscript{I} distributions are at the end.

The next class is Galaxies with H\textsubscript{I} Extensions. The first subclass is Galaxies with Two-Sided Warps. This is the perhaps the most under-represented class included in the Gallery, as warps are rather common (Bosma 1991). Here we have simply collected some representative examples. This includes the very peculiar system NGC 3718 (Fig. 13). We have placed it here because, like the two-sided warps, it has a 180° sense of symmetry, and we could not think of a more suitable place for it.

The two-sided warps are followed by Galaxies with One-Sided H\textsubscript{I} Extensions. Within this subclass are galaxies whose H\textsubscript{I} morphology is believed to be due to Ram Pressure Stripping (Figs. 21 — 26). The next system, the BCD galaxy NGC 4861 (Fig. 27), has both an extended H\textsubscript{I} envelope and an H\textsubscript{I} cloud with no optical counterpart, making it the perfect connector to the next subclass, Galaxies with Detached H\textsubscript{I} Clouds\textsuperscript{2}. This is another group of galaxies which is poorly represented in the Gallery, and many more examples appear in the literature. The qualifier “no optical counterpart” obviously depends on the quality of the existing optical data, and to hedge our bets, we have placed this classification between “H\textsubscript{I} extensions” and the next class of systems, the Minor Mergers. This way, if an optical counterpart to the H\textsubscript{I} cloud is subsequently identified, the Gallery needs not be re-ordered. Similarly, the first member of the Minor Mergers, M 108 (Fig. 30), has an H\textsubscript{I} extension toward an optical companion, but the optical companion does not have a known redshift. If it is subsequently shown to be a background object, then this system naturally falls into the prior subclass.

As just mentioned, the next class of systems is the Minor Mergers. These are two (or more) galaxies which are physically close to each other and show signs of interacting, and in which one of the galaxies is much larger or much

\textsuperscript{1}This is a somewhat circular argument, since the prime evidence for an interaction is often the extent of the gas distribution, and there are papers in the literature for nearly all of the objects in this class claiming an interacting or merging origin based on this fact.

\textsuperscript{2}We note that many of the galaxies in other parts of the Gallery have H\textsubscript{I} clouds with no identified optical counterparts, but are classified according to their most dominant H\textsubscript{I} characteristics.
brighter than the other(s). While we have by no means quantified the relative size or luminosity ratio, we estimate that the companion is of order 1/4 or less the size or luminosity of the primary. These systems are arranged in order of decreasing separation between the component galaxies. With the exception of M108, all the pairs of Minor Mergers have known redshifts which imply a physical association.

Within the class of Minor Mergers, we include several subclasses. The first is M51 Types: large grand-design spirals with small companions at the end of one of the spiral arms. The next subclass is 3-body Encounters, of which M81 (Fig. 53) is the prototype. These are different from the class of Triples later in the Gallery, as one of the participants appears much larger or brighter than the others. The Mrk348 system (Fig. 52) is a member of both of these subclasses: it has a small companion at the end of a spiral arm, and an H\textsc{i} distribution very similar to M51 (although on a much larger physical scale); but there is also a large neighbor (NGC266) to the northwest, which may have played some role in shaping the outer H\textsc{i} morphology.

After the 3-body encounters comes NGC1097 (Fig. 57), which is placed here because its companion (NGC1097A) appears ready to merge with it. This is followed by the Minor Merger Remnants. These have a single identifiable nucleus, but optical morphological peculiarities typically ascribed to strong gravitational disturbances, such as shells, ripples, tails, and plumes. They appear here, as opposed to the later class of Merger Remnants, because of the continued survival (or re-formation?) of a large disk. It is widely believed that major mergers destroy disks. While we are not convinced of this fact, the literature on these objects discusses them almost exclusively in terms of a minor merger origin, so we adopt those results here.

The next class of galaxies is the dominant class represented in the Gallery: Interacting Doubles or Major Mergers. These are galaxies of apparently similar mass which are physically associated. This classification has taken precedence over other classifications except Triples — Groups. For example, if the outer H\textsc{i} morphology appears clearly tidal in origin, we have placed the system in this class rather than under the category of H\textsc{i} Extensions.

We have subdivided this category into five separate subclasses. In doing so we draw heavily on the lessons learned in the pioneering study of interacting galaxies by Toomre & Toomre (1972; see also Barnes 1998). Specifically, from that work we learn the following: (1) tidal features first form shortly after first orbital periapses; (2) tails are formed at the rate of one per prograde disk; (3) high-inclination or retrograde encounters lead to large epicyclic motions within the disk, but do not form well-defined tails; and (4) bridges form from a wide range of encounter geometries. Further, we know that later-type spirals tend to be rich in H\textsc{i}, whereas lenticulars and ellipticals tend to be gas poor (Roberts & Haynes 1994).

With these considerations in mind, we have morphologically defined several subclasses which we think are dynamically related to the Hubble types of the participants and the spin geometry of the encounter. We emphasize that this classification is purely morphological: we have made no attempt to check the proposed spin geometries against the velocity fields of the galaxies. The subclasses are defined as follows:
Two H$\text{I}$ Systems; Two Tails: from the above dynamical considerations, we suspect that these are interactions between two prograde disk galaxies, which we indicate in Table 1 by the notation $(Sp^+ − Sp^-)$, where $Sp$ denotes a spiral progenitor, and the $+$ superscript denotes the suggested prograde spin geometry. Objects within this subclass are arranged by decreasing nuclear separation, with well-separated objects at the beginning and single objects with two tails at the end. II Zw 40 (Fig. 6) may reasonably be placed midway through this sequence, but we left it with the BCDs in the class of Galaxies with Extended H$\text{I}$ Envelopes.

Two H$\text{I}$ Systems, One H$\text{I}$ Tail: from the above dynamical considerations, we suspect that these involve interactions between two spiral disk galaxies, only one of which has a prograde geometry. The second disk might have a highly inclined or a retrograde spin geometry, indicated by a superscript 0 in the $(Sp^+ − Sp^0)$ notation in Table 1. Objects within this subclass are again arranged by decreasing nuclear separation, with well-separated objects at the beginning and single objects with a single tail at the end. Arp 295 (Fig. 159) belongs near the beginning of this sequence, but has been placed with Groups... due to its large number of H$\text{I}$ companions. The first member of this subclass, the LMC/SMC/MS system (Fig. 73), may more properly belong to the class of 3-body encounters under Minor Mergers, but we decided to place it according to the morphology exhibited in the figure. Arp 215 (Fig. 60) might reasonably be placed at the end of this sequence, rather than with the Minor Merger Remnants.

Two H$\text{I}$ Systems, Bridge, No Tails: we suspect that these involve interactions between two highly inclined or retrograde disk galaxies, denoted by the $(Sp^0 − Sp^0)$ notation in Table 1. The first members of this subclass may well have different spin geometries and be caught prior to first orbital periapse, but they fit the above morphological definition so are placed here. The galaxies in this subclass are arranged with nuclear separation first decreasing as morphological distortion increases, then with nuclear separation increasing as more bridge material appears between the two systems. Notably, there are no Merger Remnants included at the end of this sequence. Since the tidal signatures of such encounters are not as well defined, it is much harder to make a confident classification of such objects after the progenitors have merged. VV 114 (Fig. 107 under Merger Remnants) may be an example of such an object. The reader will notice that this sequence ends with Ring Galaxies, which also starts the next subclass.

Two Systems, Only One with H$\text{I}$: These are presumably encounters between one gas-rich and one gas-poor progenitor ($E − Sp$ notation). The first few systems in the subclass exhibit no tails, while the remaining systems all show one tail. The first three continue the theme of the last five systems of the previous subclass by showing Ring Galaxies, but in this case the smaller penetrating galaxy has no gas. It is possible that the gas was stripped as this system passed through the gas-rich target system, or that the progenitor was always gas-poor. In the Arp 104 system (Fig. 101) it looks like the southern system has a gas-rich tail, but the morphology of this feature resembles numerical simulations in which bridge material passes through the companion and emerges on the opposite side.
The final subclass of Interacting Doubles is that of **Merger Remnants of Indeterminate Origin**. These systems are clearly the result of the coalescence of separate stellar systems, but it is really not possible to say what has merged or how.

All of the previous classes have been dominated by late-type or spiral galaxies. The next major class, **Peculiar Early Types or Early Types with Peculiar H$_1$**, is centered around early types and ellipticals. Many of these may be Merger Remnants, others may be Minor Merger Remnants, and yet others may owe their gas and/or optical morphological peculiarities to their dense local environments. Since these origins are very difficult to distinguish, we have made subclasses based on both their optical and H$_1$ morphology.

The first subclass is **Peculiar Ellipticals with H$_1$ Outside the Optical Body**, and is ordered by the amount of H$_1$ in the outer regions (from lots of H$_1$ to no H$_1$). This sequence may be considered a possible extension of the Toomre Sequence of Major Mergers (Toomre 1977), demonstrating how gas-rich disk galaxies might fall together, merge, and leave a gas-poor bulge-dominated galaxy in their place. The amount of optical peculiarity decreases along this sequence (but not uniformly), with more subtle optical peculiarities in the later than in the earlier stages. At the end of this sequence we have included a montage of optically peculiar early types mapped in H$_1$, but in which the H$_1$ is not associated with the early type galaxy. These provide an interesting counterpart to optically peculiar systems in which H$_1$ has been detected. It is possible that more sensitive H$_1$ observations might uncover some H$_1$ in these systems, but clearly it will be less than in those that have already been detected. These systems are ordered by decreasing optical peculiarity, as quantified by the Fine Structure Index (FSI) of Schweizer & Seitzer (1992). This index quantifies the number of shells, jets, plumes, ripples, and “X”-structures, as well as the boxiness of the galaxy. We note that many of these galaxies exhibit quite striking peculiarities when imaged with modern CCDs, and the reproductions here, taken from the Digital Sky Survey, really do not do them full justice.

The next subclass is **Peculiar Early Types with H$_1$ Within the Optical Body**. These are arranged by the degree of regularity of the H$_1$. The early systems have a very irregular H$_1$ distribution, and the distribution becomes more symmetric and disk-like as the sequence progresses. This sequence demonstrates the intriguing possibility that in some cases enough cold gas is accreted onto a bulge-dominated galaxy to form (or re-form) a disk.

This is followed by **Normal Early Types with Peculiar H$_1$**. These galaxies have no obvious optical peculiarities (certainly at a much lower level than the preceding two classes), but have some very interesting H$_1$ distributions. This emphasizes the point that it is very difficult, if not impossible, to guess the H$_1$ morphology based on a system’s optical appearance. The first system of this subclass, the polar ring galaxy UGC 7576 (Fig. 130), could equally well have been the last system of the previous subclass. After this, the H$_1$ distribution becomes increasingly irregular along the sequence. Unlike the previous two subclasses, this ordering is not meant to suggest an evolutionary sequence. Rather, this ordering forms a natural transition from the disk-like H$_1$ distributions of the previous subclass, to the irregular distribution of the next class of objects.
Given the normal optical appearance of the hosts, we are not sure what to make of this subclass of objects. It is possible that future optical observations will reveal as-yet-undiscovered optical peculiarities in these systems, and that they may fit naturally into one of the previous two categories. It is also feasible that the Hi has a tidal origin, and for some reason the encounter geometry left the outer tidal gas in an irregular distribution long after the inner regions have relaxed. In this case, these systems would be an extension of the previous two categories. Yet another possibility is suggested by the fact that most, if not all, of the members of this subclass live in group environments; in this case the gas may have been stripped from the outer regions of other members and accreted onto the early type, which is usually one of the largest members of the group. These objects may therefore belong to the class of Interacting Triples — Groups — Clusters. In the latter class however the effects of interaction are manifested optically, so we have elected to keep these classes separate. The most interesting possibility (in our opinion) is that the gas in these systems was never in a galaxy, and represents accretion from a primordial reservoir. At present it is not possible to discriminate between these and other possible scenarios, but this is in any case one of the most intriguing categories of objects in the Gallery.

The next class of objects is just as interesting, comprising galaxy systems with Intergalactic Debris with No Optical Counterpart. These three objects could easily have been categorized into other classes (the Leo Ring with the previous class; NGC 5291 with peculiar early types with Hi within the optical body; and NGC 4532 with galaxies with one-sided extensions, or with the minor mergers). We have placed them into a separate category since in these cases the relation between the Hi and the neighboring galaxies is less clear.

Interacting Triples — Groups — Clusters form the next major class. As mentioned above, there are a lot of similarities between the Hi distribution seen in triples and groups and those shown in the previous three subclasses of objects, but here there are clear optical distortions suggesting more directly an interaction origin for the intergalactic gas. This class is ordered (for the most part) by the increasing number of members. The exception is at the end, where we have put three early-type-dominated groups. In each of these last three systems there is a significant extended X-ray component, which must have some effect on the presence or absence of cold gas.

Finally, there is the unavoidable Miscellaneous class. These objects do not obviously belong to any of the preceding classes, nor are there enough similar characteristics to warrant the creation of additional classes. The first examples of this class (the low-redshift QSOs and the E+A galaxy) have been called interacting galaxies, but this conclusion was based on the Hi distribution. If there is anything we have learned from the compilation of the Gallery, it is that weird Hi distributions need not always arise due to interactions.

4. Description of Gallery Figures

We have attempted to present the data in as uniform a manner as possible. To facilitate this, many users contributed the original data in FITS format. The basic Hi data are the integrated Hi intensity maps (zeroth moment), which give the integrated flux ($\int S \Delta v$; units of mJy beam$^{-1}$ km s$^{-1}$) at each location.
is usually constructed with the windowing technique to suppress the inclusion of noise (Bosma 1978). The contour levels are given in terms of the surface density, $N_{HI}$ (in units of H atoms per cm$^2$), which is obtained from the integrated flux via the equation (see Spitzer 1978, eqn. 3.38):

$$N_{HI} = \frac{1.104 \times 10^{21} \text{cm}^{-2}}{\theta_x \times \theta_y} \frac{\int S \Delta v}{\text{mJy beam}^{-1} \text{km s}^{-1}}$$ (1)

where $\theta_x \times \theta_y$ is the full-width at half-maximum (FWHM) size of the synthesized beam along the major and minor axis, measured in arcseconds, and the gas is assumed to be optically thin.

The $N_{HI}$ contour levels are given in each figure caption, and are usually separated by factors of two. For a small number of systems, it was not possible to derive contour levels.

Spectral line observations also provide line-of-sight velocity information. This information is very informative, but we have decided against its inclusion here, mostly because we had our hands full collecting the integrated intensity maps, but also because such maps beg for a color reproduction. In the future we hope to make the velocity and velocity dispersion maps available, but for the present the readers should refer to the cited literature.

The H$^i$ data is shown alongside and contoured upon optical images of each object. When available, we use existing optical CCD data, predominantly donated by the H$^i$ observers. Where optical data were not available, we use the Digitized Sky Survey (DSS) image obtained from the Space Telescope Science Institute. We use the second generation survey products when available, preferring the blue plates to the red.

There is a wealth of information available in the data, and a single format does not do it justice. We have therefore used a combination of layouts. In order to reproduce the figures at as large a scale as possible, the figure captions do not describe the figure layout, which we believe to be reasonably self-evident. The various layouts are described here. The simplest involves a greyscale representation of the optical image on the left, and the optical image with H$^i$ column density contours on the right. When the faint optical structure warrants it, we present two representations of the optical data with different transfer functions, in addition to the optical image with H$^i$ contours superimposed. Finally, when the complexity of the H$^i$ structure warrants it, we also present a greyscale representation of the integrated H$^i$ emission. These images show clearly H$^i$ minima and maxima, which may be ambiguous in the contour maps. When we do show a greyscale map of the H$^i$, we sometimes include contours. These are most often single contours from the optical data. When there are multiple contours, these are spaced by factors of ten apart. On a few occasions we show H$^i$ contours upon the H$^i$ greyscales. Since the H$^i$ and optical morphologies are so different, it should be obvious what the contours represent.

Positive H$^i$ contours are drawn with dark solid lines, and negative contours (e.g., H$^i$ absorption against radio continuum sources) are drawn with dashed and/or light lines. Occasionally a larger or smaller field of view (FOV) is also shown, to illustrate either the large-scale H$^i$ distribution, or more distant H$^i$-detected companions, or to show details of the inner regions. The smaller FOV is usually indicated by dotted boxes in the larger FOV image.
As mentioned above, the information in the figure captions is kept to a minimum. For the HI data we report the telescope (and array configuration for VLA data), synthesized beam resolution (FWHM), and contour level. For the optical data we report the telescope and filter combination, or simply “DSS” when data from the Digital Sky Survey are used, and we give for each image the approximate FOV in arcminutes. There is a section for minimal notes, and finally the reference. Unpublished data is listed as “[authors], these proceedings” with a page number. These refer either to contributions presented at the conference and collected in the first part of these proceedings, or to abstracts collected at the end of the Gallery.

In the first panel of each figure we label each galaxy with a catalog designation and the Hubble Type reported in the NASA Extragalactic Database (NED). We also indicate whether NED lists the galaxy with a Seyfert classification. These classifications have not been verified, and should only be used as rough guides. They are included because we find it interesting when galaxies classified as early types are found to have lots of HI, and when galaxies classified as spirals are found to have none or very little. Using NED we have attempted to identify all cataloged galaxies with HI detections, as well as galaxies with known redshifts which place them within the range of the HI observations. Galaxies with their names labeled in parenthesis have redshifts which put them in the foreground or background.

5. Tables

At the beginning of the Gallery we present three tables. Table 1 outlines the arrangement of the Gallery by morphological class and subclass as described in §3. It gives one line descriptions of the classes and the abbreviations used to indicate the class in Table 3.

Table 2 is the Table of Contents for the Rogues Gallery. It lists the galaxies in the order in which they appear in the Atlas, grouped by class, followed by the Figure and page number.

Table 3 presents basic information for all 432 of the cataloged galaxies labeled in the 181 images of the Rogues Gallery. The entries are listed in order of increasing Right Ascension (J2000) of the main target galaxy in the image. The galaxies are grouped by image and groups are separated by thick horizontal lines. Within a group individual galaxies are separated by thin horizontal lines. In the first two columns we list the most popular catalog names. In column three we list the J2000 coordinates and the heliocentric radial velocity (km sec$^{-1}$). All information in these first three columns is taken directly from a batch query to the NASA Extragalactic Database (NED) in July of 2001. Column 4 lists the morphological type as found in NED, the RSA (Sandage & Tamman 1987) and the RC3 catalogs (de Vaucouleurs et al. 1991). Column 5 gives the class as defined in §3 and Table 1, and the Figure and page number.

In addition to the three table mentioned above, there is a comprehensive object index at the end of this volume, which includes all objects in the Rogues Gallery.
6. Acknowledgments

We could not have compiled this collection without the generosity of dozens of H1 observers within the community. Many of these contributions came as part of the general conference, although others who were unable to attend also contributed. We would like to offer our sincere thanks to these people for making this gallery possible, and implore the reader to properly reference the original work. Specifically, this atlas has greatly benefited from the specific contributions by Tyler Nordgren, Marc Verheijen, Jim Higdon, Rob Swaters, Caroline Simpson and collaborators, Jeremy Lin, D.J. Pisano, Marcel Clemens, Carole Mundell, Salman Hameed, Eric Wilcots, Liese van Zee, Pierre-Alain Duc, Dave Hogg, Judith Irwin, Michele Kaufman, Bev Smith, Veera Boonyasait, Elias Brinks, Vassilis Charmandaris, Jayanne English, Deidre Hunter, Linda Sparke, Andrea Cox, Lourdes Verdes-Montenegro, Min Yun, Phil Appleton, Jim Condon, Michiel Kregel, Glen Langston, Tom Oosterloo, Oak-Kyoung Park, Mary Putman, Rich Rand, Arnold Rots, Sue Simkin, Lister Staveley-Smith, Athanasios Taramopoulos, Helen Thomas, Wei-Hao Wang, and Barbara Williams. We also thank Garrett Bauer and Karen Yeh for adding the FOVs to the image captions.

The VLA is a facility of the National Radio Astronomy Observatory, which is operated by Associated Universities Inc. under cooperative agreement with the National Science Foundation.

The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The Oschin Schmidt Telescope is operated by the California Institute of Technology and Palomar Observatory. The UK Schmidt Telescope was operated by the Royal Observatory Edinburgh, with funding from the UK Science and Engineering Research Council (later the UK Particle Physics and Astronomy Research Council), until 1988 June, and thereafter by the Anglo-Australian Observatory. The plates were processed into the present compressed digital form with the permission of these institutions.

The National Geographic Society - Palomar Observatory Sky Atlas was made by the California Institute of Technology with grants from the National Geographic Society. The Second Palomar Observatory Sky Survey was made by the California Institute of Technology with funds from the National Science Foundation, the National Geographic Society, the Sloan Foundation, the Samuel Oschin Foundation, and the Eastman Kodak Corporation.

This research has made extensive 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.

References

Arp, H.C. 1966, ApJS, 14, 1
Arp, H.C. & Madore, B.F. 1975, Observatory, 95, 212
Arp, H.C. & Madore, B.F. 1987, “A Catalog of Southern Peculiar Galaxies and Associations,” Cambridge University Press.

Barnes, J.E. 1998, in Saas-Fee Advanced Course No. 26, “Galaxies: Interactions and Induced Star Formation”, R.C. Kennicutt, Jr., F. Schweizer, & J.E. Barnes (Springer, Berlin), 275

Bosma, A 1991 in “Warped Disks and Inclined Rings Around Galaxies”, S. Casertano, P. D. Sackett, & F. H. Briggs (Cambridge University Press, Cambridge)

Bosma, A. 1978 PhD thesis, University of Groningen

Broeils, A.H. 1992, PhD thesis, University of Groningen

Cayatte, V., van Gorkom, J.H., Balkowski, C., & Kotanyi, C. 1990, AJ 100, 604

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H., Buta, R., Paturel, G., & Fouque, P. 1991, Third Reference Catalogue of Bright Galaxies (Springer, New York) (RC3)

Malin, D.F. & Carter, D. 1983, ApJ, 274, 534

Martin, M.C. 1998, A&AS, 131, 73

Oosterloo, T. 1988, PhD thesis, University of Groningen

Roberts, M.S. & Haynes, M.P. 1994, ARAA, 32, 115

Roberts, M.S. & Rots, A.H. 1973, A&A, 26, 483

Sandage, A. & Tamman, G.A. 1987, “A Revised Shapley Ames Catalog of Bright Galaxies” (Publ. 635; Carnegie Inst. Washington, Washington, DC)

Schweizer, F. & Seitzer, P. 1992, AJ, 104, 1039

Spitzer, Jr., L. 1978, Physical Processes in the Interstellar Medium (John Wiley and Sons, Inc., NYC)

Struck, C. 1999, Phys Rep, 321, 1

Swaters, R. A., 1999, PhD thesis, University of Groningen

Toomre, A. 1977, in The Evolution of Galaxies and Stellar Populations, ed. B.M. Tinsley & R.B. Larson (Yale University Press, New Haven), 401

Toomre, A. & Toomre, J. 1972, ApJ, 405, 142

van Driel, W., & van Woerden, H. 1991, AA, 243, 71

Verheijen, M. A. W., & Sancisi, R. 2001, A&A, 370, 765

Vorontsov-Vel’yaminov, B.A. 1959, “Atlas and Catalogue of Interacting Galaxies” (Moscow).

Vorontsov-Vel’yaminov, B.A. 1977, A&AS, 28, 1

Warmels, R.H. 1988, A&AS, 72, 19

Wevers, B.M.H.R., van der Kruit, P.C., & Allen, R.J. 1986, A&AS 66, 505