# The Distribution of Low Surface Brightness Galaxies in the Pisces-Perseus Supercluster


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## *Abstract*


*We present results from our new HI observations of more than 70 "blue edge" galaxies in the field south of the Pisces-Perseus Supercluster (PPS) ridge performed with the Arecibo 305m. These "blue edge" galaxies, selected from the Minnesota Automated Plate Scanner Catalog of the POSS I, have been previously identified as the high surface brightness end of the population of low surface brightness galaxies (Cabanela & Dickey 2002). As such, they are good Low Surface Brightness galaxy (LSB) candidates. We detected roughly 65% of the observed LSB candidates in HI with cz between 0 and 12000 km $s^{-1}$.*

*Since over 1000 "normal" galaxies in the PPS field have already had their redshifts determined (mostly by Giovanelli, Haynes, and collaborators), we can compare the distribution of the now over 100 known LSBs in this single supercluster field with the known large-scale structure for the supercluster. This allows a more detailed examination of the environment LSBs call home than previous studies which relied on a few hundred LSBs scattered over several steradians of sky (a la Bothun et al. 1993 or Mo et al. 1994). Our initial results support those earlier studies which suggested that LSBs trace out the same large-scale structures as "normal" high surface brightness galaxies.*



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## Our Motivation

- What little we know about the process of galaxy formation suggests that **galaxies formed from density perturbations** in the early Universe.

- If the initial density perturbation spectrum was Gaussian, the **majority of perturbations that survive to this day should be smaller ones** which would form low-density galaxies such as Low Surface Brightness Galaxies (LSBs). **In fact, LSBs are likely a major repository of baryons in the Universe, containing many more baryons than the observed high surface brightness galaxies (HSBs).**

- Therefore, **LSBs should be relatively isolated on small scales** (to allow the survival of their small density perturbations into modern times), **but otherwise they should trace out the same mass distribution seen in "normal" HSBs.** Previous studies have supported this prediction through comparisons of the positions and relative densities of LSBs to HSBs in all-sky surveys.
  - First noted by Davis and Djorgovski (1985) who showed that the lower surface brightness galaxies from the Uppsala General Catalog (UGC) were less tightly clustered than their high surface brightness counterparts.
  - Bothun (1998) notes that on scales of $\leq 2\ h^{-1}$ Mpc LSBs are relatively isolated, whereas on scales of $\geq 5\ h^{-1}$ Mpc they appear to trace out the same structures as HSBs.

- **However, no one has done a detailed study of the comparative distributions of LSBs and HSBs in a single supercluster. This is in large part due to the fact that the number of known LSBs in any one supercluster is generally small.**


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## Our Approach: Identify LSBs in One Supercluster

Instead of an all-sky approach, we performed a more focused study of the LSBs in a smaller field covering the Pisces-Perseus Supercluster. The fields surrounding the Pisces-Perseus Supercluster are some of the most well-probed regions of the sky in terms of redshift observations thanks to the efforts of Giovanelli, Haynes and collaborators (*eg.* Giovanelli and Haynes 1988). Because the large-scale structure of the Pisces-Perseus Supercluster (as delineated by "normal" HSB galaxies) is fairly well understood, it makes a more thorough analysis of the distribution of LSBs relative to the large-scale structure in this field more straightforward. Rather than relying on a few hundred LSBs scattered over several steradians of sky (a la Bothun *et al.* 1993 or Mo *et al.* 1994), we could observe many LSBs confined to a relatively small (but well understood in terms of resident large-scale structure) field, allowing us to perform a more detailed examination of the environment LSBs call home.

**The only initial difficulty is quickly identifying LSBs in the Pisces-Perseus Supercluster field**, a problem we believe we have resolved using the methods outlined by Cabanela & Dickey (2002) **[See the box on "LSBs on the POSS I" below]** Once the LSB candidates in the Pisces-Perseus Supercluster field have been identified, it is simple to take directed 21cm observations of these galaxies to determine estimates of their gas mass to light ratios and other physical properties.

## Target Selection and Observations

- LSB candidates were identified in the Minnesota Automated Plate Scanner (MAPS) Catalog of the Palomar Observatory Sky Survey (POSS I) using the following criteria:
  - The objects selected had to be identified as "galaxies" by the MAPS artificial neural network image classifier on both the Blue (O) and Red (E) plates of the POSS I and have E magnitudes brighter than 20.
  - The objects needed to lie on the "blue edge" of MAPS color-magnitude parameter space distribution of galaxies **[See the box on "LSBs on the POSS I" below]**.
- Since the Arecibo telescope has a beam with a FWHM of ~3 arcminutes at 1400 MHz, we used the Digitized Sky Survey of the POSS I to visually inspect the 6x6 arcminute field around each candidate to eliminate those in which confusion could pose a problem. This also allowed us to eliminate candidates which were not galaxies but misclassified plate defects or diffraction halos around bright stars.
- We observed 156 LSB candidates in the Pisces-Perseus Supercluster using the L-band narrow receiver at the Arecibo 305m radio telescope in September and November of 2002.
  - We used four staggered 25 MHz wide bands overlapping by 5 MHz to provide velocity coverage from 0 to 18000 km $s^{-1}$ (1340 to 1420 MHz).
  - Observations done in 5 minute on-off pairs to obtain (on-off)/off spectra for each source. Some candidates were re-observed due to heavy radio-frequency interference (RFI).
  - Assuming a system temperature ~30K, our 5 minute observations have limits of 22mK per 24 kHz channel.
  - Assuming a minimum line width of 50 km/s, this gives **a 3σ HI mass detection limit of roughly $1.9\times10^9$ $M_{solar}$ at the distance of the Pisces-Perseus Supercluster ($cz \sim 5000$ km $s^{-1}$).**
- **The majority of candidates (55%) observed were detected in HI.**

**Figure 00:** Two examples of high density baryonic matter in the local universe, Zakari William (left) and Carolina Rosa (right) Cabanela, born on October 23, 2002 to the PI and his wife, Catherine Cabanela.

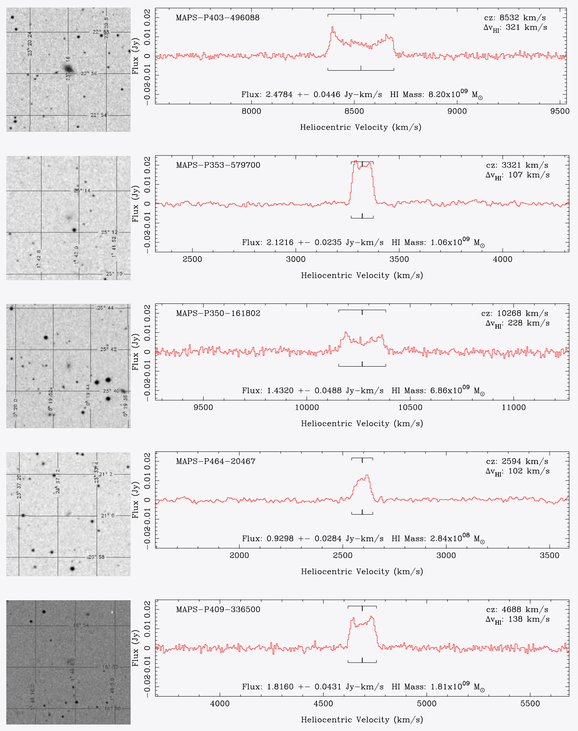



**Figure 1:** 6x6 arcminute Digital Sky Survey images and HI spectra for LSB candidates with the five highest gas mass to blue light ($M_{HI}/L_O$) ratios.

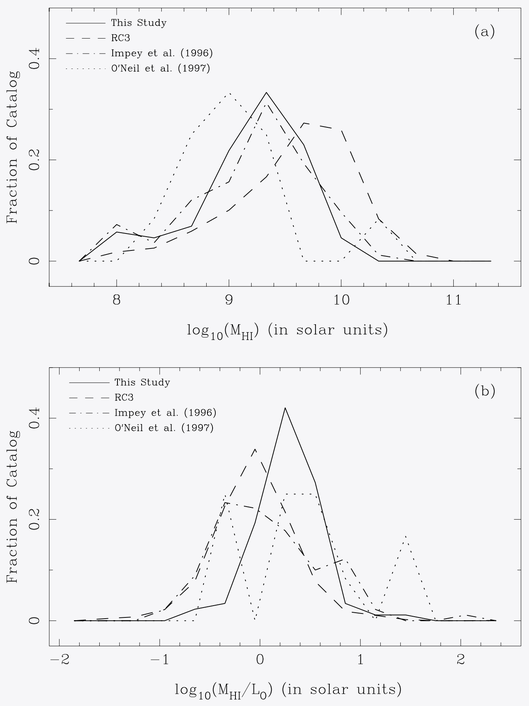



**Figure 2:** The distribution of HI masses and gas mass to blue light ($M_{HI}/L_O$) ratios for our LSB candidates compared to the Reference Catalog of Bright Galaxies (RC3), and the O'Neil *et al.* (1997) and Impey *et al.* (1996) LSB catalogs. The galaxy catalogs all had their samples restricted to galaxies with $cz < 18000$ km $s^{-1}$ and their optical luminosities were determined using MAPS catalog O (blue) magnitudes for consistency.

## Initial Results

Due to complications beyond our control (the birth of the PI's twins, see Figure 00), the data reduction was delayed until recently. However, the spectra for the majority of the galaxies have been reduced and initial conclusions regarding the nature of these galaxies can be derived:

- The majority of our LSB candidates were indeed detected in HI although many lie "behind" the Pisces-Perseus Supercluster which lies at a redshift of ~5000 km $s^{-1}$ (See Figure 1).
- Our LSB candidates share HI mass and gas mass to blue light ratios ($M_{HI}/L_O$) similar to the LSB catalogs of O'Neil *et al. (*1997) and Impey et *al. (*1996) but very different from the Third Reference Catalog of Bright Galaxies (RC3). **This suggests our LSB candidates are indeed LSBs or possibly a transitional population between HSBs and very low surface brightness galaxies** (See Figures 2 and 3).
- The redshift space distribution of our detected LSB candidates is very similar to that of the the known HSB galaxies in the field identified from the CfA Redshift Catalog (See Figure 4). The actual density of the environments of LSBs versus HSBs has not yet been determined.

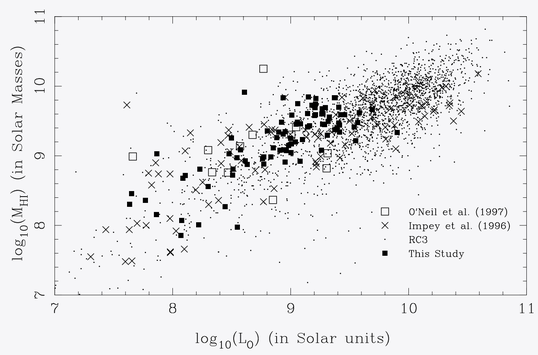



**Figure 3:** HI mass versus blue luminosity for our LSB candidates compared to the same galaxies as in Figure 2. Notice that our LSB candidates for the most part lie between the HSBs in the RC3 and the known LSBs in the O'Neil *et al.* (1997) and Impey *et al.* (1996).

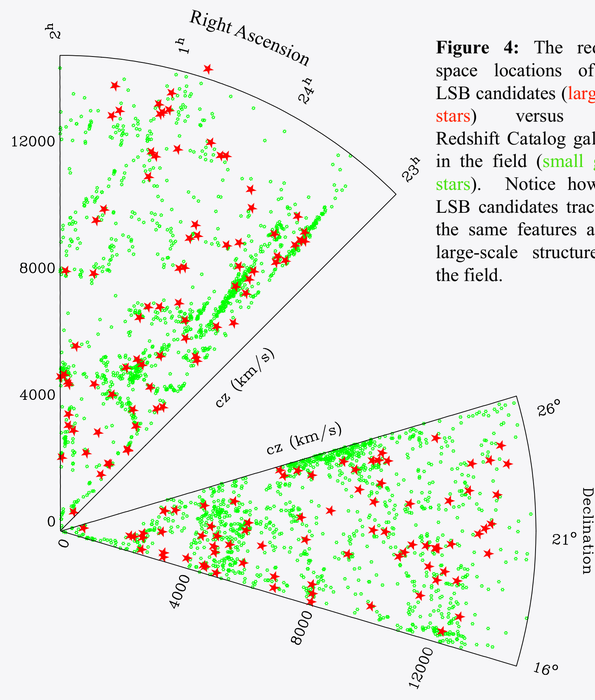
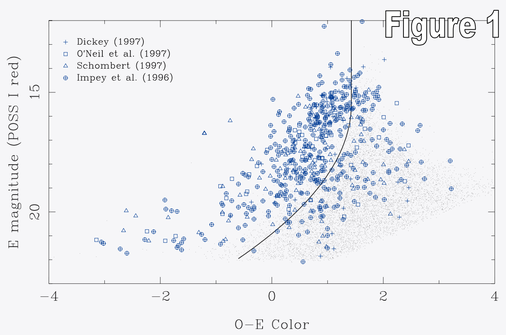



**Figure 4:** The redshift space locations of our LSB candidates (large red stars) versus CfA Redshift Catalog galaxies in the field (small green stars). Notice how the LSB candidates trace out the same features as the large-scale structures in the field.

## LSBs on the POSS I




- Over 65% of LSBs on the POSS I lie blueward of the bluest 10% of "normal" APS galaxies (indicated by the dark curving vertical line), **including those "red" (in B-V) LSBs from O'Neil, Bothun, and Cornell!**

Key Point

**LSBs, at least those actually visible on the POSS I, can be identified optically based on their location in POSS I color-magnitude parameter space.**

### Why LSBs Appear Blue on the POSS I

- In the MAPS Catalog of the POSS I galaxy colors are determined from the integrated Blue (O) and Red (E) magnitudes down to the plate limit.
- The Blue emulsions exhibit deeper limiting surface brightnesses than the Red emulsions.
  - This difference in limiting surface brightness has little effect on the colors of high surface brightness galaxies (like those in the RC3).
  - However, LSBs from OBC have systematically lower POSS I fluxes than implied by their reported B and V magnitudes **(see Figure 2)**.
  - **Figure 3** shows these differences lead to **lower surface brightness objects having bluer colors on the POSS I.**