eaa.iop.org
DOI: 10.1888/0333750888/2620

Low Surface Brightness Galaxies

Erwin de Blok

From

Encyclopedia of Astronomy & Astrophysics

P. Murdin

ISBN: 0333750888

Institute of Physics Publishing
Bristol and Philadelphia

Low Surface Brightness Galaxies

Low surface brightness (LSB) galaxies are galaxies that emit much less light per area than normal galaxies. Because of their lower contrast with the night sky they are hard to find, and hence their contribution to the general galaxy population has long been underestimated.

Galaxies with low surface brightnesses are hard to find because the night sky is never black. Scattered sunlight coming from dust inside and outside our atmosphere, air-glow, street lights, faint Galactic and extra-Galactic sources all illuminate the sky. This foreground and background glare acts as a filter that only lets us see a part of the total galaxy population.

Compare this with the example of a person sitting inside a brightly lit room at night. This person will have trouble seeing what is happening outside because of the bright reflections of the room in the windows. Only the brightest objects (e.g. headlights of cars) will be easily visible. Headlights of bicycles, or pedestrians will be very hard to make out, even though they may dominate the traffic outside. The bright reflections thus filter out large parts of the total population.

In more practical terms, selection effects caused by the brightness of the night sky have made astronomers only give attention to those galaxies that were most easily observed. The underlying reason for these selection effects is that galaxy catalogs are usually created using certain isophotal diameter and/or magnitude limits (with an additional implicit surface brightness limit). The brightness of the night sky ensures that galaxies of a certain fixed luminosity look largest, and are thus most easily seen, if their central surface brightness has some intermediate 'optimum' value. If they have higher surface brightnesses they look too compact and resemble stars; with lower surface brightnesses they are difficult to distinguish from the night sky.

Diameter- or magnitude-limited catalogs thus mainly contain galaxies with a narrow range in central surface brightnesses. They will be biased and incomplete for galaxies with central surface brightnesses other than the 'optimum' value.

In the following, galaxies that are not affected by selection effects and that have an optimum value for detection are called 'high surface brightness' (HSB) galaxies. For all practical purposes these can be equated to the well-known SPIRAL GALAXIES that define the Hubble sequence. The dimmer galaxies that are affected by selection effects are called LSB galaxies. Examples are shown in figure 1.

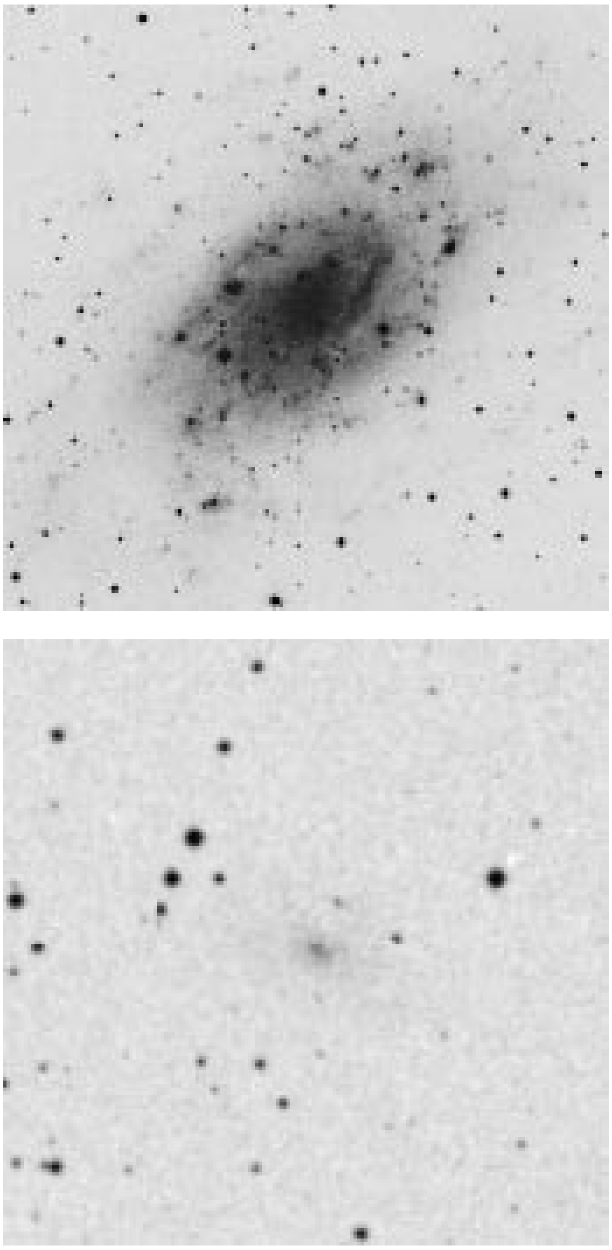

Figure 1. An HSB galaxy (NGC 2403, left panel) and an LSB galaxy (UGC 128, right panel) with identical luminosities, shown at the same physical scale, and observed with the same instrument. As the light of the LSB galaxy is much more spread out it is harder to distinguish from the glare of the night sky.

Selection effects

The best way to get a feeling for the severity of selection effects is by discussing a practical example. We will discuss five different types of model galaxies, which approximately span the currently known range in structural properties of DISK GALAXIES. All are assumed to be pure exponential disks, with central surface brightnesses μ_0 and scale lengths h as given in table 1. Four of these galaxies (A, B, C and D) have identical luminosities $M_B = -21$. The fifth one, E, is equal in size to galaxy B, but 2.5 mag or a factor of 10 fainter. It is furthermore assumed that all five types are spread through space homogeneously and in equal numbers. In each volume element there are therefore an equal number of different types of galaxies.

We will now 'observe' these galaxies and create a

Table 1. Contribution of various galaxy types in diameter-limited catalog.

Type[a]	M_B[b]	h[c]	μ_0[d]	D_{max}[e]	Fraction	
A	−21.0	0.5	16.0	60	0.09	Compact HSB
B	−21.0	5.0	21.0	125	0.72	Normal HSB
C	−21.0	25.0	24.5	76	0.18	Big LSB
D	−21.0	50.0	26.0	—	0.00	Giant LSB
E	−18.5	5.0	23.5	30	0.01	Normal LSB

[a] Type of galaxy. [b] Absolute magnitude. [c] Scale length in kpc. [d] Central surface brightness in mag arcsec^{-2}. [e] Maximum distance in Mpc where galaxy is included in catalog. [f] Fraction of cataloged galaxies that will be of this type.

diameter-limited catalog. The condition for inclusion in the catalog will be that the diameter of the 25 mag arcsec^{-2} isophote D_{25} must be larger than 1 arcmin. It is obvious that galaxies at large distances will look smaller than those nearby. Therefore, as we examine each type of galaxy and move it to increasingly larger distances, its D_{25} will at some point become less than 1 arcmin, and consequently it will no longer be included in the catalog. The distance where galaxies of a certain type drop out of the catalog is given in table 1: galaxy A will drop out of the sample at 60 Mpc; galaxy B will be in the sample out to distances of 125 Mpc; galaxy C out to 76 Mpc. Galaxy D has no D_{25} diameter and will never be taken up in the catalog. Finally, galaxy E will be seen only out to 30 Mpc.

Galaxies of type B correspond to normal HSB galaxies, while type E represents typical LSB galaxies. Type C is a big LSB galaxy. Types A and D are in practice rare. Cataloged HSB galaxies (such as B) can be detected in a volume 72 times larger than the volume in which LSB galaxies (such as E) can be detected. Assuming that all types of galaxies are spread equally through space, the corresponding volumes cataloged galaxies occupy show that the catalog will be severely dominated by HSB galaxies of type B and will lead to the conclusion that almost three-quarters of the total galaxy population consists of type B. Only an apparently insignificant 1% of the galaxies in the catalog are of type E. Furthermore, we would not even know that giant galaxies, such as type D, existed. On the basis of these results we would conclude that three-quarters of the observed galaxy population had a constant central surface brightness.

To correct for these effects we must therefore realize that every LSB galaxy that *is* cataloged represents a large number of uncataloged LSB galaxies. This means that we must assign to every galaxy a weight inversely proportional to the volume in which it is included in the catalog. Hence, if we try to reconstruct the true galaxy population from this diameter-limited catalog, every LSB galaxy of type E must receive a weight 72 times larger than a galaxy of type B. Note though that we still would not be able to say anything about type D. These volume-correction factors are crucial for our understanding of LSB galaxies.

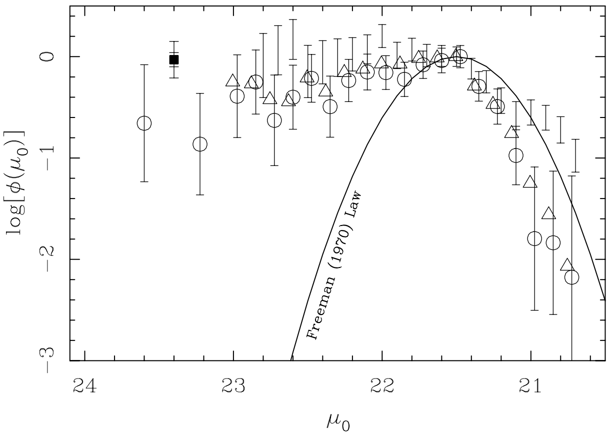

Figure 2. The number density of galaxies plotted versus central surface brightness. There is a large excess of galaxies at the LSB side of Freeman's value.

History

Selection effects and their possible consequences did not receive much attention until 3 decades ago. Before that only incidental references appeared in the literature. HUBBLE noted in 1936 that intrinsically faint galaxies will be detectable to much smaller distances than intrinsically bright galaxies and are consequently distributed through a much smaller volume of space. Thus 'intrinsically bright nebulæ greatly outnumber the faint ones among nebulæ with a given *apparent* luminosity'. In 1938 SHAPLEY announced the discovery of two intrinsically faint LSB galaxies, and in 1965 Arp showed that most galaxies then investigated occupied only a very narrow strip in a luminosity–diameter diagram; implying that they have almost identical surface brightnesses.

This last conclusion was explicitly derived by Freeman in 1970 who noted that 28 galaxies out of his sample of 36 had disks with central surface brightnesses in the range $\mu_0^B = 21.65 \pm 0.3$ mag arcsec^{-2}. Taken at face-value, this result had important implications for theories of GALAXY STRUCTURE and EVOLUTION. Freeman's law requires that either all galaxies have identical mass surface densities coupled with just a small spread in their mass-to-light ratios or that STAR FORMATION history, age, angular

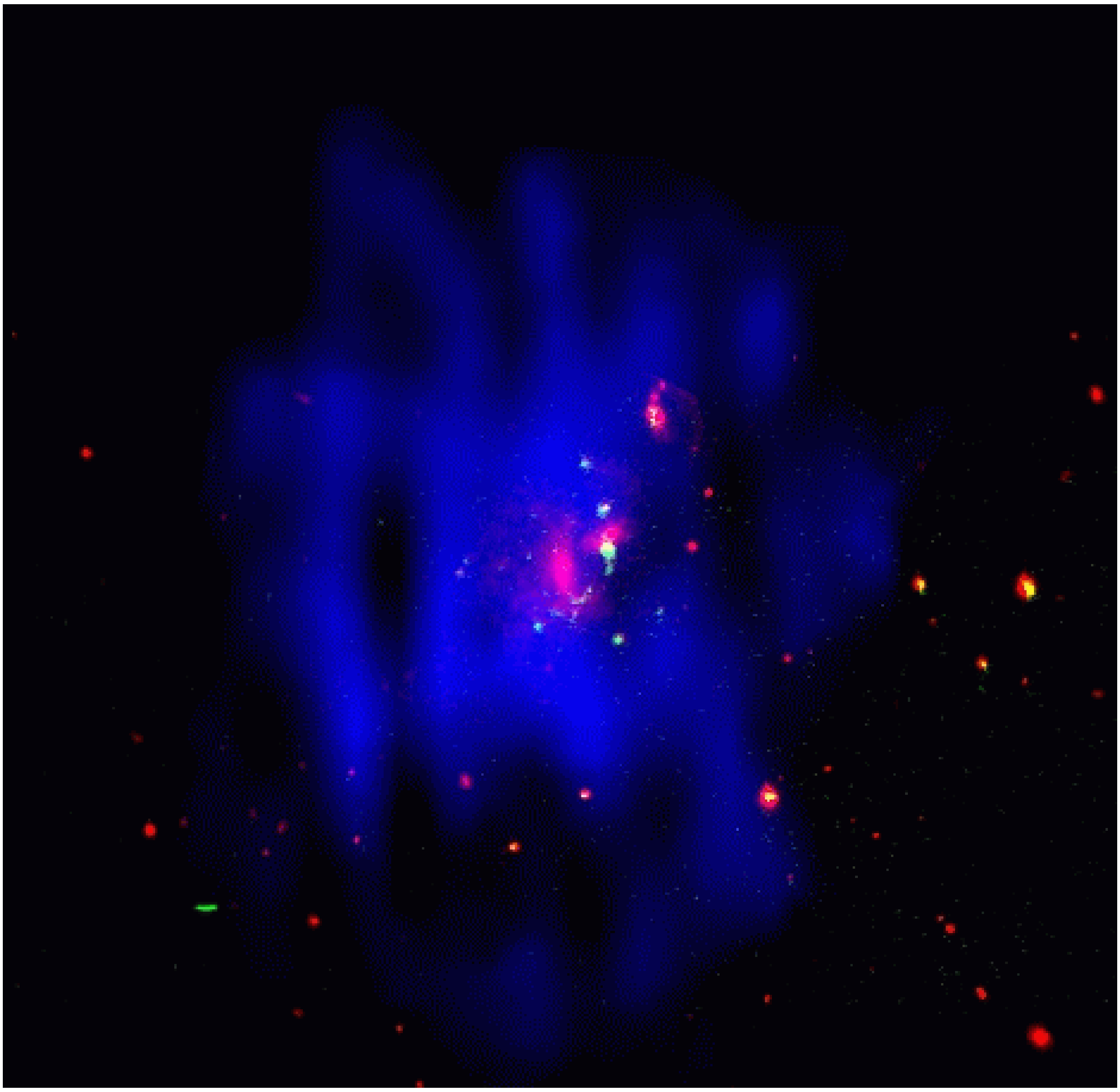

Figure 3. LSB galaxy F563-1. This false-color image is a combination of optical, 21 cm radio and 6563 Å Hα spectral-line observations. The red false colors show the stars in LSB galaxy F563-1 observed though a red filter. Blue false colors show the extent of the large and diffuse disk of neutral hydrogen surrounding the optical galaxy. The green–yellow dots in the center are observed in the light of the Hα spectral line at 6563 Å, showing the few star formation regions in this galaxy. The red and yellow dots surrounding the galaxy are foreground stars. The gas and stars in this galaxy represent a mass of a few billion solar masses, yet this is only a small fraction of the mass of the huge dark matter halo that surrounds this galaxy. This galaxy is at a distance of 45 Mpc or 147 million light-years. The diameter of the neutral hydrogen disk is 43 kpc or some 140 thousand light-years. **This figure is reproduced as Color Plate 12.**

momentum and mass all conspire to produce a constant central surface brightness

Disney in 1976 showed that selection effects could cause Freeman's law and suggested that there might be many galaxies of both high and low surface brightness ('crouching giants') hidden below the night sky. The discovery in 1987 of the giant LSB galaxy Malin-1 put LSB galaxies in the limelight. This extremely large and massive LSB galaxy was discovered accidentally during a survey for small LSB galaxies in the VIRGO CLUSTER. Malin-1 has a central disk surface brightness 4 mag arcsec^{-2} fainter than Freeman's value, yet it has a scale length of tens of kpc, a luminosity $M_B \simeq -22$ and an H I mass of slightly less than $10^{11} M_\odot$. This did show that LSB galaxies were not necessarily small and faint dwarf galaxies.

Careful searches on photographic survey plates then started turning up LSB galaxies in large numbers. These galaxies were mostly of late type and rich in hydrogen.

After correction for various selection effects one of the conclusions was that the space density of LSB galaxies at $\mu_0 = 23$ is approximately 10^5 times higher than predicted by Freeman's law (figure 2).

The currently known LSB galaxies ($25 < \mu_0(B) < 23$) may make up 30–50% of the total galaxy population.

Properties

The properties of LSB galaxies can be summarized as follows.

They are more gas rich than HSB galaxies. One of the probable reasons they have lower surface brightnesses is because their gas surface densities are well below the critical threshold density for star formation. LSB galaxies thus have very low star formation rates. Although following the large-scale structure of galaxies, they are locally more isolated than other galaxies.

Investigations of the colors of LSB galaxies showed that they were bluer than normal late-type galaxies. Combined with the low metallicities found in H II REGIONS this implies a sporadic star formation rate, ruling out the notion of LSB galaxies as 'faded disks'. LSB galaxies are not normal galaxies which have stopped forming stars and are now fading away. Instead, they are likely to be slowly evolving. The contrast of the few young stars with the old background population, or, in other words, the rate of current star formation rate and average past star formation rate are much higher than in normal HSB late-type galaxies. A small amount of recent star formation (as observed) is already enough to make the colors significantly bluer.

Synthesis observation in the neutral hydrogen 21 cm line (see figure 3) confirmed this unevolved picture: LSB galaxies have extended gas disks with low gas surface densities, and high $M_{\rm HI}/L$ ratios. Despite the low surface densities the gas component is usually dynamically more important than the stellar component.

LSB galaxies are on the same TULLY–FISHER RELATION as HSB galaxies. This requires a subtle interplay between the central luminosity surface density Σ_0 and the total mass-to-light ratio M/L. As the Tully–Fisher relation can be written as $L[\Sigma_0(M/L)] \propto V^4$, the product $\Sigma_0(M/L)$ must be constant for all galaxies on the Tully–Fisher relation. LSB galaxies must have higher mass-to-light ratios than normal galaxies.

The rotation curves of LSB galaxies showed that this was indeed the case. LSB galaxies are DARK MATTER dominated almost all the way into their centers. The rotation curves rise less steeply than those of HSB galaxies. The halos of LSB galaxies are likely to be of lower density than those of HSB galaxies. The large dark matter dominance makes the stellar disks of LSB galaxies extremely stable, making it possible for the disk to exist at such low surface densities. The low metallicities make cooling difficult, so that a molecular component, where stars are formed, is difficult to realize. LSB galaxies can be said to be trapped in their current evolutionary state. Even external influences, like interactions, might not be enough to significantly speed up the evolution of LSB galaxies.

The above results apply to blue LSB galaxies that have been discovered in photographic plates. Recent CCD surveys (see also DETECTION OF FAINT OBJECTS) have started turning up a class of red LSB galaxies, showing that even the deep photographic plates suffered from selection effects. However, not enough is known about these red LSB galaxies to be able to say whether they are a cosmologically significant component of faded galaxies.

Importance

The single most important reason for studying LSB galaxies is that no representative sample of nearby galaxies has yet been compiled, cataloged and investigated. If a large population of hitherto unseen objects exists, the true extent of galaxy properties may be much larger than assumed.

Furthermore, investigations of individual LSB galaxies show that they form an alternative track of galaxy evolution, free from the instabilities and interactions that have shaped the Hubble sequence. They give us the opportunity to study unevolved galaxies in great detail.

Bibliography

Two good reviews on which this article has largely been based and which contain all relevant references are

Bothun G D, Impey C and McGaugh S S 1997 Low-surface-brightness galaxies: hidden galaxies revealed *Publ. Astron. Soc. Pac.* **109** 745–58

Impey C and Bothun G D 1997 Low surface brightness galaxies *Ann. Rev. Astron. Astrophys.* **35** 267–307

Erwin de Blok