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Low Surface Brightness Galaxies Beyond Z = 0.5: Existence, Detection and Properties

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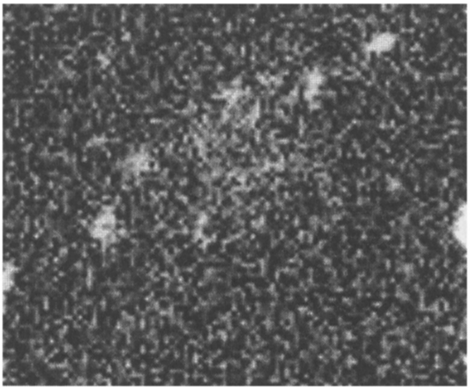
Abstract.

I argue that low surface brightness disks evolve sufficiently slowly that, at any redshift, there should be a high space density of these objects. Cosmological dimming, in combination with the tenacity of Freeman's Law, will make their direct detection very difficult. Given their abundance at z =0, it seems reasonable to suggest that such hidden galaxies will be important absorbers along the line of sight to distant QSOs.

1. Introduction

This talk is a complete exercise in speculation (see also Bothun et al 1997). Why? Well a) because its easier than trying to be definitive and b) no data yet exists on the topic to even build a position, let alone defend it. Let's begin with my concept of what a low surface brightness (LSB) galaxy is. A prime example is shown in Figure 1 which is one of the more extreme LSB objects discovered in O'Neil (1997a).



SDSSPDM-1

The reason to introduce the topic with this object is two fold: a) this is exactly the kind of object which will be a challenge for the Sloan Digital Sky Survey (SDSS) to detect (PDM stands for Please Detect Me) and b) how can objects like this be detected at all at moderate redshift due to $(1+z)^4$ surface brightness dilution? The severity of this term will likely be borne out when surface photometry is done on some of the disk galaxies in the Hubble Deep Field. So in some sense were done already. Cosmological dimming will simply exacerbate the already severe selection effects present at $z = 0$ in the detection of LSB galaxies and hence this topic can be confined to a single page. However, a single page of speculation is not very interesting so let's press on.

2. Surface Brightness Evolution

Clearly the distribution of disk galaxy surface brightness at any redshift depends upon the rate of surface brightness evolution. Galaxy evolution is usually defined in terms of luminosity, size or color evolution but these are a sub-set of surface brightness evolution. The observed surface brightness is the convolution of the average spacing of stars, the stellar luminosity function and the amount of dust that is present. Hence, LSB galaxies could be so because of:

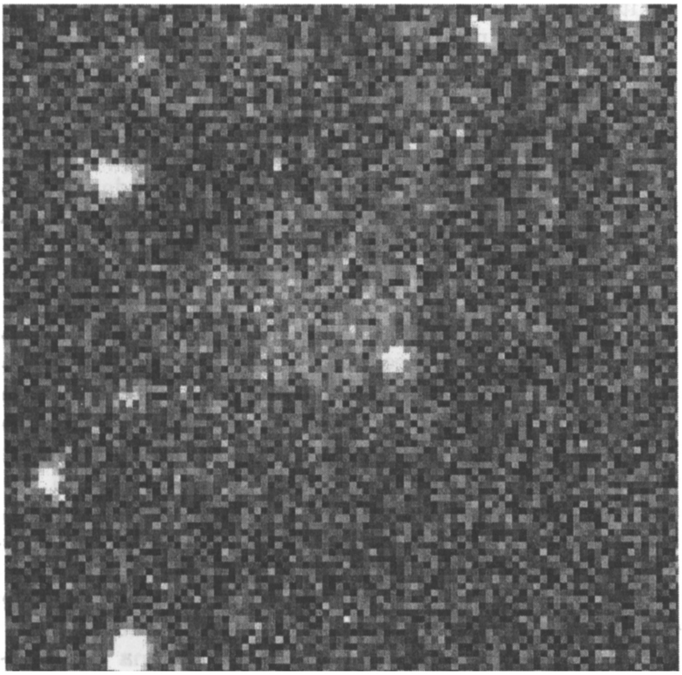
- Low mass density (an argument favored by de Blok and McGaugh 1996) which leads to large stellar separation
- A high M/L stellar population (e.g. low luminosity per unit baryon mass)
- High obscuration (although Witt et al 1992 clearly show that forward scattering by dust is sufficient so that the outgoing optical luminosity can not be suppressed by more than about a factor of 2).
- Something else.

A useful thought experiment is to consider the long term surface brightness evolution of galaxies. They are born as baryonic gas bags inside of some dark potential and thus start off as LSB as few stars have formed. Eventually, we can expect the disk to run out of gas to make stars (although Tully in this conference has stated that disk galaxies won't do this but continue to operate in some low recycling level) and then it will begin to fade significantly. A portion of this fading process might have already occurred and this could account for the population of red LSB disks recently discovered by O'Neil et al 1997b (see also O'Neil 1998 - this conference).

3. Freeman's Law is Not Easy to Break

As is well known, Freeman's Law establishes that the typical disk galaxy you find in a survey has a central surface brightness about 1 mag brighter than the sky background. In the blue the typical value for the sky background (at a dark site) is 22.5 - 23.0 mag arcsec^{-2}. Freeman's Law would then suggest the typical disk which is selected would have $\mu_B(0) \sim 21.5$ mag arcsec^{-2}. This was the essence of Disney's (1976) original argument. This conference exists largely because Freeman's Law has been broken and even astronomers outside this conference now actually believe that LSB galaxies exist. In fairness to Freeman, his data sample of the time (Freeman 1970) did contain IC 1613, a genuine LSB galaxy by all accounts (see McGaugh and Bothun 1994). Scrutiny of Freeman's result was motivated by the puzzling implication it had for galaxy formation. Namely, it would mean that the physics of disk galaxy formation is rather finely tuned to produced a preferred mass density disk over a larger range of scale lengths.

Now we know that the range of central surface brightness in disk galaxies at a given scale length is large (de Jong 1998 - this conference) . To first order, this implies large variance in the amount of dissipation, baryonic drag and angular momentum transfer that must occur during the initial collapse phase. Although its possible to model this, the input physics is unclear and the relevance of objects such as that shown in Figure 1 is to demonstrate that extremely diffuse flattened galaxies did, apparently form. I claim no understanding of how such diffuse systems either exist or survived a Hubble time of potential galaxy harassment. Given the extreme difficulty of discovering such diffuse systems, and here I mean objects with $\mu_B(0) = 25.0$ mag arcsec^{-2}and fainter, implies that if you found a few, there must be many. Below is an example of another member of the SDSSPDM class.



SDSSPDM-2

As a testimony to how even more difficult the detection of this population would be at modest redshift, consider an interesting result contained in O'Neil et al 1999. Those authors performed a surface photometry analysis of 210 galaxies in 3 deep WFPC2 frames. The data was all taken through the 814W filter. Most of the detected galaxies are disks with scale lengths of 0.2 to 1.5 arcseconds. The 814W sky brightness was measured to be 23.0 mag arcsec^{-2}(which is equivalent to a Cousins I-band sky brightness of 21.8 mag arcsec^{-2}). The median central surface brightness obtained for the fitted disks was 814W(0) = 21.9 mag arcsec$^{-2}\Rightarrow$ 1 magnitude brighter than the sky background. Thus, even with a much different detector and observing system, a random sample of galaxies returns Freeman's result. This directly confirms the tenacity of visibility function induced selection effects.

4. Once an LSB Always an LSB?

If star formation in some disk galaxies is episodic in nature, would it be possible for LSB disks to migrate out of this category as "bursts" of star formation serve to elevate the surface brightness. One immediate problem with what seems to be a reasonable scenario is the lack of any color vs. surface brightness relation for disk galaxies. As documented by O'Neil et al (1997b) even at the very lowest levels of central surface brightness, both very red and very blue disks can be found. Another problem may arises if we take the surface mass density argument to its extreme. If $(\delta\rho/\rho)_{gas} \propto (\delta\rho/\rho)_{stars}$ (an unproven assumption) then low values of $\mu_B(0)$ mean low gas densities. Under these conditions, the Jeans length can be 1-2 disk scale lengths (because the low gas density requires a large scale length for the gas mass to exceed the Jeans mass).

The physics of star formation that would occur in this regime is probably very different than that which governs the fragmentation of Giant Molecular Clouds in the ISM of HSB disks. For those disk galaxies detected to date with $\mu_B(0) \sim 25.0$ mag arcsec^{-2}, this begs the question, how could stars ever form in the first place in such a low density environment? Current attempts to explain this as a result of star formation in small clumps of molecular gas (e.g. Spaans 1998 - this conference) don't seem destined to account for all the stars that presently exist in these systems. On a global scale, LSB disks have been shown to be significantly deficient in molecular material and dust (e.g. Schombert et al 1990; de Blok et al 1996) yet they seem to contain as many stars as those galaxies where we know that star formation is occurring in GMCs. This basic point seems under-appreciated. It certainly obscures whether or not star formation would follow a Schmidt Law in LSB disks.

O'Neil et al (1998) have made some toy models to simulate the effects of weak tidal encounters and the initiation of star formation in localized regions of a LSB disk. The starburst strength is 15% of total galaxy gas mass that is available. The key feature of these models is that the low gas density means limited formation of high mass stars as there is a low probability of sufficient gas mass per model cell. Thus, in this scheme there is a natural suppression of high mass star formation and one does wonder if this is the relevant physics of star formation in a low density environment. This suppression of massive star formation would lead to a low rate of chemical evolution of the disk and an under-production of dust mass over a Hubble time. The color and luminosity evolution of such a disk would also not be very dramatic as a result of induced star formation. All of these predicted properties seem to be borne out by the observations to date of LSB disks. This produces the expectation that LSBs are docile over time and never are the hosts of monster starbursts that might drive the evolution of higher surface brightness disk galaxies.

This also means that once $\mu_B(0)$ is low, it will remain low. This directly implies that the space density of LSB disks should be relatively large at all redshifts. This has obvious implications with respect to the kinds of galaxies that produce the observed QSO absorption lines. The two views adopted at this conference were 1) All QSO absorption lines originate in the halos of big galaxies (e.g. Lanzetta 1998) or 2) LSB galaxies make up a substantial portion of the absorbers because the overall space density of galaxies is higher than we think it is (e.g. Linder 1998). Resolution of these two views requires more data. However, it is instructive to remember what Mateo and Armandroff have told us at this conference: halos around big galaxies contain several LSB objects!

To get more substantial evolution in $\mu_B(0)$ requires a model in which there is a threshold $(\delta\rho/\rho)_{gas}$ that is maintained by disk galaxies, independent of their value of $\mu_B(0)$. This allows galaxies to have a larger reservoir of gas to be processed into stars thus increasing their luminosity/color evolution. While the existence of this threshold is actually supported by real observations (Skillman et al 1987, van der Hulst et al 1993, Pickering et al 1997), no disk with $\mu_B(0)$ fainter than 23.0 mag arcsec^{-2}has been mapped at 21-cm. If the threshold argument is correct, this should become self-evident in the Parkes Multi-Beam Survey.

5. Summary

1. Surface brightness selection effects are already severe at z =0. The discovery of z > 0.2 LSB disks will be a challenge because Freeman's Law is robust.

2. The rate of surface brightness evolution of disk galaxies is not well known but it seems reasonable to expect that some disk galaxies have made the bulk of their stars and are beginning to fade. The red LSBs detected by O'Neil et al (1997b) may be the first z=0 detection of this population.

3. Preliminary modeling of the response of an LSB disk to induced star formation indicates that the formation of massive stars is suppressed due to the low initial gas density. This implies a low rate of chemical and surface brightness evolution for these disks and a preservation of their space density over a large range in redshifts. Potentially, these disks are a major contributor to QSO absorption line systems.

4. All disk galaxies are destined to become LSB high M/L systems. I propose that we all come back to Wales in 10 billion years and count the number of LSB galaxies struggling for detection against the noisy background sky.

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