THE DISTRIBUTION OF YOUNG STARS IN NEARBY GALAXIES

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1. INTRODUCTION

Although luminous stars are relatively rare, they can potentially be studied out to large distances. In our own Milky Way, this advantage is offset by obscuration due to dust in the plane of the Galaxy. In addition, distances to these individual stars are extremely difficult to determine. The study of external galaxies allows a panoramic view of the system and its individually brightest stars which are all at a common distance. The spatial distribution of star forming regions is immediately apparent, and the effects of obscuration are minimized. Nearby resolved galaxies therefore provide a rich resource for examining the properties of the intrinsically brightest stars and their relation to other components of the galaxy.

Spectroscopy of stars in external galaxies will be covered in other reviews in this volume. Therefore, this review will concentrate on studies of photometry in galaxies near enough that stars can be resolved in them. Studies of luminosity functions, spatial distributions of young stars, and comparison with the distribution of gas, and radial distributions of stars in external galaxies will be discussed.

2. STELLAR PHOTOMETRY OF BRIGHT STARS IN NEARBY GALAXIES

Much of the work on stellar photometry in external galaxies has recently been reviewed by Scalo (1985a) and Freedman (1984), and will not be repeated here. Instead, below are tabulated studies in which photometry of bright stars in external galaxies have been obtained. Included also for reference, is the type of study (photographic (pg), photoelectric (pe), or CCD).

C. W. H. De Loore et al. (eds.), Luminous Stars and Associations in Galaxies, 61–80.

Table 1

Nearby Galaxies with Stellar Photometry

Galaxy	Type	References	Study
M31	Sb	Reddish (1962)	pg
		Baade and Swope (1963)	pg
		Freedman (1986)	CCD
		Humphreys (1986)	pg
M81	Sb	Sandage (1984a)	pg
		Freedman (1984, 1986)	pg, CCD
M33	Sc	de Vaucouleurs (1961)	pg
		Madore (1970, 1978)	pg
		Reddish (1978)	pg
		Humphreys and Sandage (1980)	pg
		Freedman (1984)	pg, CCD
		Freedman *et al*. (1986)	pg, CCD
NGC 2403	Sc	Tammann and Sandage (1968)	pg
		Sandage (1984b)	pg
		Freedman (1984, 1986)	pg, CCD
M101	Sc	Sandage (1983)	pg
		Humphreys and Strom (1983)	pe
IC 1613	Irr	Sandage and Katem (1976)	pg
		Hodge (1978, 1980)	pg
		Freedman (1986)	CCD
NGC 6822	Irr	Kayser (1967)	pg
		Hodge (1980)	pg
		Freedman (1986)	CCD
Sextans A	Irr	Reddish (1978)	pg
		Hoessel, Schommer and Danielson (1983)	CCD
		Freedman (1984, 1986)	CCD
Ho I, II	Irr	Hoessel and Danielson (1985)	CCD
Ho IX	Irr	Sandage (1984)	pg
		Freedman (1984, 1986)	CCD
LMC	Irr	Shapley (1931)	pg
		de Vaucouleurs (1955, 1956)	pg
		Westerlund (1961)	pg
		Hodge (1961)	pg

		Lucke (1972)	pg
		Butcher (1977)	pg
		Rousseau et al. (1978)	pe
		Hardy (1978)	pg
		Stryker (1981)	pg
		Stryker and Butcher (1982)	pg
		Hardy _et_ _al._ (1984)	pg
SMC	Irr	Ardeberg and Maurice (1977)	pe
		Hardy and Durand (1984)	pg

3. LUMINOSITY FUNCTIONS IN NEARBY GALAXIES

Until recently, the data on luminosity functions in nearby galaxies was inhomogeneous, and, in many cases, photometry was available for only small samples of stars, often obtained for purposes other than the construction of luminosity functions. This problem is beginning to be solved with the advent of fast plate-measuring machines, and software analysis programs for obtaining photometry in crowded fields.

It must be stressed however, that the study of luminosity functions in even the nearest galaxies is limited to the very brightest stars alone; therefore no direct information is acquired about the low-mass end of the luminosity function outside of our own Galaxy. Furthermore, no information is obtained on possible variations of the luminosity or mass function with time. However, such studies do offer the advantage of allowing a comparison of the bright end of the luminosity function in a wide range of environments, having differing metallicities, kinematics, amounts of present star formation, total mass of system, etc.

3.1 Comparison of Luminosity Functions

There are conflicting interpretations of the data in the literature concerning whether or not real variations exist in the slope of the luminosity function comparing one galaxy to another. The first systematic comparison of published luminosity functions was recently undertaken by Scalo (1985a). Scalo finds that there is a remarkable agreement between the luminosity functions of the stars in M33, M31, NGC 6822, IC 1613, the LMC and SMC. Many cases where differences have been previously claimed are shown to be marginal, especially in view of the magnitude of the statistical uncertainties and the variety of methods used to obtain and reduce the data in the various studies. He concludes that the available data for $M_v < -3$ mag is consistent with a galaxy-wide universal luminosity function.

Freedman (1984) obtained UBV prime focus plates at the Canada-France-Hawaii telescope (CFHT) for M33, NGC 2403, and M81, and at Cerro Tololo for NGC 300. Positions, magnitudes, and colors were measured for several thousand images over the face of each of these galaxies using the Automatic Plate Measuring (APM) machine (see Kibblewhite et al. 1984). In addition, BVRI CCD data were obtained at the Kitt Peak 4m and the CFHT 3.6m for several fields in each of M33, NGC 2403, Ho IX, Sextans A, and Leo A.

The upper end of the main-sequence luminosity function is populated by hot, luminous, blue stars. Thus, apparent luminosity functions based on stars of all colors may be relatively insensitive to differences in the upper end of the mass function. Therefore, luminosity functions were constructed with a sample of only the bluest stars in each galaxy, as determined from their U-V and B-V colors. An additional advantage to restricting the sample to the bluest stars is that foreground contamination by stars in our own Galaxy is virtually eliminated. V, B and U (when available) luminosity functions were obtained.

Figure 1 presents V luminosity functions for the blue stars in 10 nearby galaxies. The data for M33, NGC 2403, M81, NGC 300, Holmberg IX, Sextans A, and Leo A are from Freedman (1984). Data for the LMC, SMC and NGC 6822 are from Rousseau et al. (1978), Ardeberg and Maurice (1977), and Kayser (1967), respectively. The data are displayed on an arbitrary number scale, as a function of absolute visual magnitude, M_V.

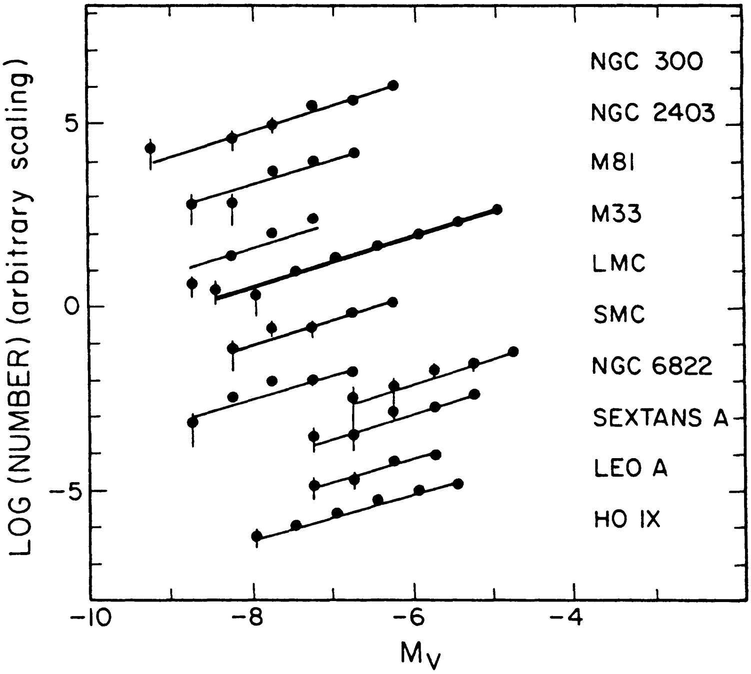

Figure 1 - The slope of the upper end of the luminosity function for a sample of ten nearby galaxies.

From this plot, the similarity of the slopes of the luminosity functions for this sample of galaxies is immediately evident over the range of absolute magnitude studied ($-9 < M_V < -5$ mag). The slope of the upper end of the luminosity function shows little variation from one galaxy to another. The largest deviations from universality occur at the brightest end where the numbers of stars are low. In addition, caution should be exercised in interpreting any of the apparent upper magnitude cut-offs because of uncertainties in the adopted distances to these galaxies. Due to the small numbers however, random errors are expected to be much larger at this end, and the data remain consistent with a universal slope for the upper end of the luminosity function.

It is also found that the slopes of the B and U luminosity functions also show little change from galaxy to galaxy. Although in general, it might be expected that the B and U luminosity functions might more accurately reflect differences in the mass function of the hottest stars, it should be recalled that all of the V luminosity functions shown here are based on a sample of the bluest stars in each galaxy. Thus these V luminosity functions are not for the visually most luminous stars, but for the bluest luminous stars.

3.2 The Slope of the Luminosity Function with Radius in M33

It is of interest to compare the slope of the luminosity function as a function of radius, particularly in galaxies with measured abundance gradients. Terlevich and Melnick (1983) have presented evidence based on a study of giant extragalactic HII regions that the slope of the mass function is a function of metallicity.

Conflicting evidence has been presented for the case of the change in the slope of the initial mass function as a function of galactocentric radius in our Galaxy. Garmany, Conti, and Chiosi (1982) have claimed that the slope of the galactic initial mass function is steeper in the region at distances beyond the distance of the sun. Based on a study of young clusters, Burki (1977) concludes also that the initial mass function in our Galaxy varies as a function of radius; however he finds the gradient in the opposite sense to that claimed by Garmany, Conti and Chiosi (1982). Scalo (1985a) has reanalyzed the data from the Garmany, Conti and Chiosi O-star catalog and concludes that the catalog is incomplete at the faint end. However, correcting for incompleteness in the Galaxy remains a difficult problem. Humphreys and McElroy (1984) have recently made an attempt to correct the counts, and find that there is no evidence for a change of slope with radius in the Galaxy. Further, they conclude that the slopes of the stellar mass functions are similar for the Galaxy, the LMC, and the SMC.

Berkhuijsen (1983) determined the slope of the luminosity functions for a number of Humphreys and Sandage (1980) associations in M33. She found factors of two variation in the slope, suggesting that the luminosity function within M33 is varying as a function of radius, and therefore, by implication, as a function of metallicity.

In a recent study, Diaz and Tosi (1984) compare available data on oxygen abundances in the Galaxy, M31, M33, M83, and M101 with chemical evolution models. They note that in any galaxy evolution model, the adoption of such radially varying initial mass functions would significantly affect the oxygen gradient predicted (since oxygen is produced mainly by massive stars). They find that agreement of the models with the observations is good using oxygen yields derived from stellar evolution models including mass loss, but for all five galaxies, the computed slope of the gradient is consistent with observations when a uniform initial mass function is adopted.

The number of stars measured in M33 is now sufficiently large that statistically reliable slopes can be calculated as a function of radius. This comparison is of interest since M33 has a measured abundance gradient (e.g., Blair and Kirshner 1985, and references therein). Luminosity functions for 4 regions at various radial distances in M33 are shown in Figure 2.

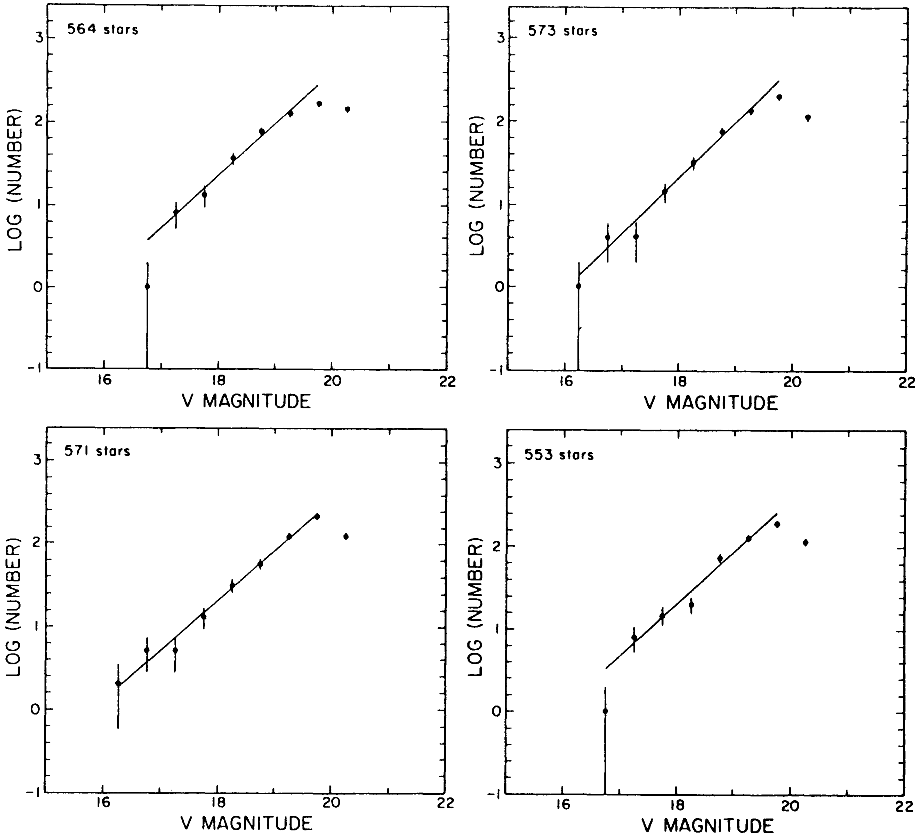

Figure 2 - The slope of the upper end of the luminosity function shown in 4 radial bins in M33.

As can be seen, there is no evidence for any statistically significant change in the slope of the luminosity function as a function of radius in M33. In addition, these data are consistent with there being no dependence of the slope on metallicity. For M33, allowing for the maximum formal uncertainty in the slopes, a correlation of the slope of the luminosity function with metallicity for M33, gives $|\Delta(\text{slope})/\Delta z| < 0.3$ at the two-sigma level (see Freedman 1985 for details). This is significantly lower than the strength of the correlation suggested by Terlevich and Melnick (1983), who found that $\Delta(\text{slope})/\Delta z = 1$, based on their study of extragalactic HII regions.

3.3 Initial Mass Functions

In principle, the derivation of the initial mass function from a luminosity function is straightforward; however, many practical difficulties exist. For high-mass stars, masses are difficult to obtain from photometry, since the colors of massive stars are not very sensitive to luminosity. Due to the longer wavelength baseline, ultraviolet (e.g., U-V) colors are more informative than B-V colors, but do not completely alleviate the problem. Ideally, spectra of large numbers of stars are needed in order to place stars in a theoretical HR diagram, from which masses can then be derived. Practically, this is a very difficult and time-consuming task; however studies of this kind are now underway (e.g., Conti, Garmany, and Massey 1985, private communication). Even once spectra of large samples of stars are obtained, large uncertainties remain in the bolometric corrections, effective temperature scales and also in theoretical tracks for the most massive stars. Theoretical uncertainties in mass loss, opacities, convection, and the importance of overshoot (e.g., see Stothers and Chin 1980) remain in all approaches to this problem, and lead to basic uncertainties in any derived initial mass function.

The difficulties in, and the different approaches to, obtaining mass functions have been discussed in detail by Scalo (1985a), and will not be repeated here, except to summarize his conclusions. Scalo finds that, given the differences in the different methods, and the uncertainties in the calibrations, there is excellent agreement amongst the methods, whether photometric, or spectroscopic. Scalo (1985b) also concludes that all of the available luminosity functions for nearby galaxies are consistent with a universal initial mass function, independent of metallicity. The uncertainty in his derived slope of the mass function is judged to be less than about ±0.3.

While the recent studies discussed above appear to indicate that large relative differences are not present in the mass function for massive stars, improved bolometric corrections and effective temperature calibrations, as well as improved theoretical evolutionary models are clearly needed before the absolute initial mass function can be accurately determined.

3.4 Problems Remaining and Future Work

The sample of galaxies now needs to be extended to include earlier Hubble types. The numbers of stars measured in many of the galaxies also needs to be increased to improve the statistics and further investigate the limits to the universality of the slope of the observed luminosity function. A larger, statistically reliable, sample of stars needs to be obtained for other galaxies with observed gradients in addition to M33, (such as M101) in order to investigate whether or not such galaxies might exhibit gradients in the slopes of their luminosity functions. A CCD study of this kind is now underway. Further, statistically reliable samples of stars within individual associations in the nearest galaxies should be obtained to conclusively determine whether or not variations exist on relatively small spatial scales within galaxies.

Within the uncertainties, the slope of the upper end of the luminosity function shows little variation. However, the uncertainties are such that 15 percent variations in the slope from galaxy to galaxy may have gone undetected. It will therefore be of considerable interest to obtain data on more galaxies, and to obtain larger samples of stars for many of the galaxies which have been discussed here in order to improve the statistics and decrease the uncertainties. In particular, the reliability of the M81 calibration must be checked, since no faint magnitude sequence was available for this galaxy. Such programs are now being undertaken.

At present, the result remains that within the uncertainties, there is no evidence for significant departures from universality for the slope of the upper end of the luminosity function.

4. RADIAL DISTRIBUTIONS IN EXTERNAL GALAXIES

It has been known for some time that the total disk light of spiral galaxies can be well represented by an exponential distribution (e.g., de Vaucouleurs 1959, Freeman 1970). More recently, the CO distributions in late-type spirals have been found to follow the exponential profiles of the integrated blue light (Young and Scoville 1982a,b), and the Hα and integrated light distributions also exhibit a close correspondence (DeGioia-Eastwood et al. 1981, Hodge and Kennicutt 1983).

Late-type Scd galaxies, which have been mapped in CO, show a close correspondence in their radial distributions with the optical blue surface-brightness distributions. The HI distribution displays a distinctly flatter radial distribution for these same systems (e.g., M101, M51, NGC 6946 and IC 342). For the Galaxy and M31, a ring of CO is observed, as well as a hole in the HI distribution. In NGC 2841 and M81, central HI holes are also present. To date, the galaxies displaying central holes tend to be early-type systems which have larger bulges than later-type galaxies, indicating that a causal connection may be present, perhaps through the resulting differences in their rotation curves and/or plane thicknesses induced by the bulge.

Freedman (1984) compared the radial distributions of blue light, HII regions, OB stars, Wolf-Rayet stars, supernova remnants, and neutral hydrogen in M33. Wevers (1984) obtained integrated light and neutral hydrogen distributions for a sample of 16, mainly late-type galaxies.

The results of all of the above studies illustrate that the neutral hydrogen distributions are significantly flatter than the distributions of recent star formation constituents (e.g., OB stars, HII regions and Wolf-Rayet stars), the molecular gas distributions, as well as the integrated light distributions.

The integrated blue light of a galaxy contains a contribution both from the young stellar population and an old disk giant population with an age of 1-3 billion years. The correspondence between the OB star, HII regions, Wolf-Rayet stars, supernova remnants and the integrated disk light suggests that the star formation rate at present does not differ from the past rate, and specifically, that star formation has not proceeded at a rate proportional to the mean gas density with some power greater than unity. If star formation had proceeded at such a rate, then one would expect that the total gas content at the center of the galaxy, (where the mean density of gas is greatest), would be depleted due to star formation, at a faster rate than in the outer regions of the galaxy where the mean gas density is lower. In such a case, the young stellar population would not be reflecting the distribution of the old disk light, but would exhibit a flatter radial profile. In fact, the HI displays a distribution that one might expect to see if the star formation at the center were proceeding at a higher rate than in the outer regions.

The apparent discrepancy between the implications of a relatively flat neutral hydrogen gas component and the steeper radial distributions of recent star formation constituents and of molecular gas late-type spirals is a challenge to present theories of galaxy evolution. Young and Scoville (1982a,b) conclude, on the basis of the similarity of the CO and blue light distributions, that the star formation rate per nucleon is a constant. However, this hypothesis cannot simply account for the strong galactic abundance gradients observed in galaxies. A closed model where the rate of star formation proceeds linearly with the gas density predicts a linear increase of the abundance with time, and no change with radius. That abundance gradients are observed implies that star formation cannot have proceeded linearly with gas density as a function of time, over the extent of the disk, for a simple closed model.

Four possible alternatives which might explain this discrepancy are listed below.

1. The yield is not constant as a function of radius. Gusten and Mezger

(1983) consider a bimodal star formation model which could produce a variable yield and thus explain the observed abundance gradients for the case where star formation proceeds linearly with gas density. Larson (1985) has also recently discussed a bimodal star formation model, in order to account for the unseen mass in the solar neighborhood.

2. Radial gas flow or infall. For a recent review, see Lacey and Fall (1985). Lacey and Fall find that for our Galaxy, they can fit the observed age-metallicity relation, the radial abundance gradient, star formation rate, and total surface density of gas (HI plus H_2) and stars, when radial flows at velocities of less than about 1 km/sec are assumed.

3. The CO/H_2 ratio may vary as a function of radius in galaxies. Bhat _et al._ (1985) and Harding and Stecker (1985) have recently presented evidence based on studies of the gamma-ray distribution in the Galaxy which suggests that the CO/H_2 ratio increases toward the galactic centre, and that the mass in molecular gas has been significantly overestimated. However, even if, in the extreme, the HI and H_2 distributions turn out not to be too significantly different, the flatter distribution of gas with respect to recent tracers of star formation (HII regions, OB stars, Wolf-Rayet stars) still remains to be explained.

4. The conversion of HI into H_2 proceeds faster at the center of the galaxy.

Two apparently contradictory alternatives seem to be present, both of which leave unexplained observations. 1) The _total_ gas content has a distribution similar to the recent star formation, and the star formation rate proceeds linearly with gas density. This explains the observed radial distributions of all constituents except the HI, and also fails to account for abundance gradients. 2) The efficiency of conversion of gas into stars is higher in the center relative to the outer regions. This naturally explains the abundance gradients, but first begs the question as to why the efficiency is higher. Second, if the total gas content is being depleted at a faster rate in the center, then why don't the newly formed stars follow the flatter, depleted, total gas distribution, but instead exhibit a steeper gradient, similar to the integrated light.

In summary, recent observations of the radial distributions of gas, young objects and the integrated light from an older population in late-type galaxies reveal that these distributions are all very similar. The implication is that the star formation histories in these galaxies have been the same for the last few billion years. Spiral galaxies exhibit abundance gradients, indicating that more processing per unit mass has occurred toward the center. The causal relationship between the neutral hydrogen distribution and other young Population I tracers is still far from clear. These issues remain at present, as unexplained problems in our understanding of galaxy evolution.

5. CORRELATION OF STARS WITH GAS: SCHMIDT'S LAW

The relationship between the rate of star formation and physical properties of the interstellar gas is a critical parameter in galactic evolution studies. Many attempts have been made to parametrize the rate of star formation. Some of the first such attempts were made by Mathis (1959), Schmidt (1959), and Salpeter (1959), who proposed that the rate of star formation is proportional to a power, n, of the gas density. This parametrization has come to be known as Schmidt's *law*. It is by no means clear that the rate is dependent upon gas density *alone*, nor even predominantly so (e.g., see Schmidt 1962, 1963, Larson 1977, Talbot 1980 and Young and Scoville 1982a,b). Nevertheless, the parametrization is often used.

Many attempts to check the validity of Schmidt's law and to search for correlations between the *surface* densities of gas and young objects in external galaxies have followed, despite the fact that Schmidt's original law correlated ρ, the *volume* density of gas with the rate of star formation. Apparently convincing observational support of this rate of star formation law has come from studies of this type of correlation, beginning with the study by Sanduleak (1969) who outlined a method for interpreting the correlation of HI gas with the density of young stars. Other studies by Hartwick (1971), Talbot (1971), Einasto (1972), Madore, van den Bergh and Rogstad (1974), Hamajima and Tosa (1975), Tosa and Hamajima (1975), and Guibert, Lequeux, and Viallefond (1978), investigating this correlation for several nearby galaxies have found that n generally has a value near 2. Madore (1977) investigated some of the assumptions which go into this correlation, and found that the true value of n actually differs from the observed value, leading to a lower value closer to 0.5 . A more detailed review of these studies is given in Freedman (1984).

Figure 3 illustrates the correlation between the HI and OB star distribution by plotting the HI and OB densities for every bin. The data are binned at a resolution of 150 x 150 arcsec. The HI data are from Newton (1980), and the stellar data from Freedman (1984). There is a tremendous scatter present in the Figure, with the stellar/HI densities spanning a large range at any given HI/stellar density. The primary source of the scatter is intrinsic; it is not due to observational error. However, the presence of scatter in this plot should not be surprising. Stars are known to be forming out of molecular gas. Thus if the gas in a region of star formation is in molecular form, no HI will be detected. Second, when high-mass stars form, they ionize the gas around them. Again this decreases the amount of HI that one would expect to observe in the vicinity of OB stars. Further, stars may migrate away from their birthplaces, which again will offset any correlation between gas and young stars. Thus one would expect appreciable scatter in any *a posteriori*, spatial comparison of HI and young stars. While an apparently good *mean* correlation does exist (see Figure 4), Figure 3 illustrates more clearly that the correlation is not a very tight one. From this plot, it is evident that the HI is not a very good detailed tracer of the most recent star formation in M33.

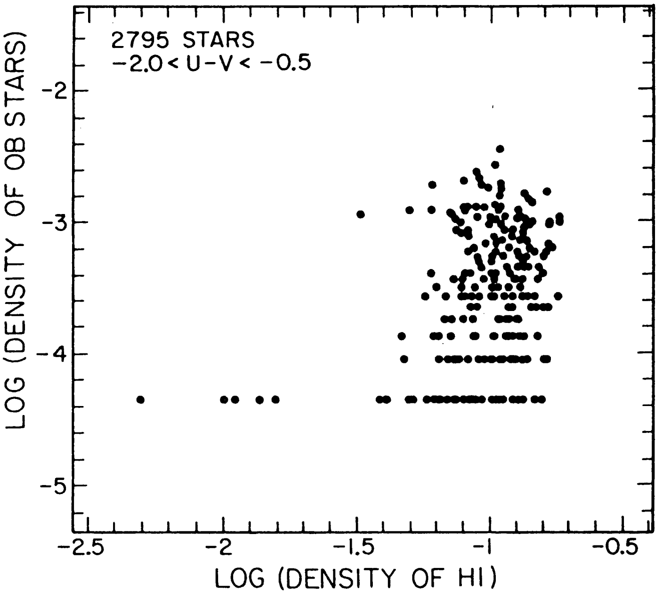

Figure 3 - The HI density versus OB star density (at a resolution of 150 x 150 arcsec) for M33.

The correlation between the distributions of the mean OB star density at ten equally spaced HI density levels in M33 is shown in Figure 4a. The correlation is an excellent one with a slope obtained from a linear least squares fit of y upon x of 2.31 ± 0.18. It would therefore seem that Schmidt's law has been verified: the rate of star formation is proportional to the square of the gas density, in agreement with the many prior studies discussed previously. Figure 4c is a plot of the correlation between the mean OB star density at mean HI density levels, again for the data in M33. In this case however, the data have now been binned at a different resolution. Generally, the beam size of the HI map has set the resolution for the published correlation studies. In Figure 4c, the resolution has been set by that of the HI study of Newton (1980), 47 x 93 arcsec. In this case, the slope is 1.29 ± 0.09. In Figure 4a, the same data was binned at a resolution of 150 x 150 arcsec, and in this case gave rise to a value of n = 2.31.

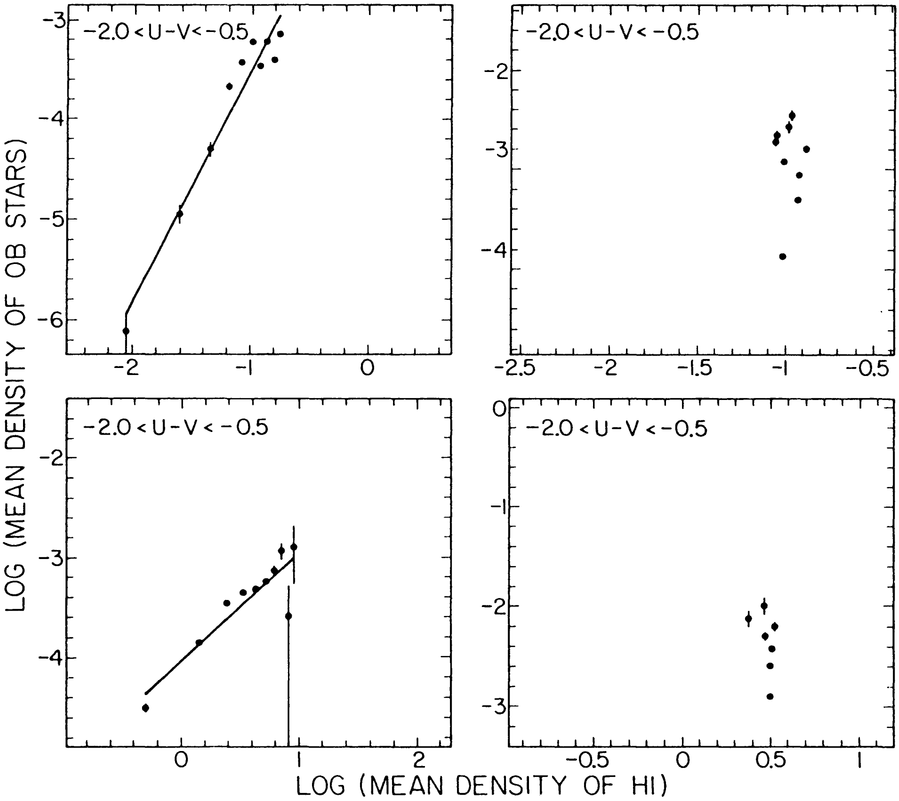

Figure 4 - The correlation of the mean OB star density at 10 given HI levels (a) at a resolution of 150 x 150 arcsec, (c) 47 x 93 arcsec. Figures (b) and (d) correspond to Figures (a) and (c), but here the data have been binned at mean OB star density levels rather than mean HI densities.

Apparently, the value of n derived depends on the size of the resolution element at which the data is binned. The imposed beam-size or binning is not necessarily related to a physically meaningful scale size at which star formation is occuring in a galaxy, and extreme caution must therefore be used in interpreting such correlations. Moreover, since the slope of the correlation is dependent on the size of the bin chosen (or imposed) on the data, it would appear that the method of attempting to derive a value for the exponent n in this manner is invalidated.

The above results illustrate some of the difficulties to be expected in attempting to determine observationally, the exponent in Schmidt's Law. Unfortunately, the derived exponent is seen to be a strong function of the spatial resolution adopted rather than being representative of the underlying relationship. In retrospect it is now apparent that this shortcoming was evident in the published literature. For instance, Newton (1980) obtained lower values of n for M33 than Madore, van den Bergh and Rogstad (1974) who used lower resolution HI data, but the same HII region data. For M31, the trends are more dramatic. Most recently, Unwin (1980) determined a value of $n = 1.37$, significantly smaller than the value of $n = 2.23$ obtained by Emerson (1974), based on the same HII data, but correlated with lower resolution neutral hydrogen maps. Earlier, Hartwick (1971) used HI data with a resolution of 600 x 660 arcsec, and obtained a much higher value of $n = 3.50$. Lower values of the correlation exponent were obtained for M31 as higher resolution HI maps were obtained.

For the same galaxies, significantly different values of n have been published. The changes can be directly attributed to the resolution of the neutral hydrogen surveys. If information about the rate of star formation is to be derived from such studies, then a physically relevant scale for the appropriate correlation needs to be defined, in terms of the star formation process rather than being defined by the technical limitations on the collected data. Until that time, the values of n published in the literature appear to be without physical content, and thus provide no concrete basis for a theoretical understanding of the rate of star formation.

The problems associated with determining the value of n are not limited to those due to the choice of bin size. A further problem is apparent when one also attempts to obtain a linear least squares fit by binning the data at mean OB star densities, (y) rather than at mean HI densities, (x). For a tight correlation, the two slopes will of course be consistent. If there are errors in x and/or y however, the two different correlations will give different slopes. Unless the errors in x and y are known, the true value of the slope of the correlation cannot be determined without bias.

Figures 4b and d (right panels) illustrate the correlations obtained in the case of first binning at mean OB densities, and then determining the mean HI density at that stellar density. Traditionally, the method has been to bin at mean HI densities; however, it is not clear which axis should be preferred (for a good correlation, the choice of the sense of the regression should be immaterial). In this case however, the slope obtained depends strongly on which axis is chosen for the binning.

In summary, the method of correlating mean HI densities with mean OB star or HII region densities, in order to test the validity of Schmidt's Law, has been shown to be invalid. Furthermore, a consideration of the the total gas density (if the molecular density is known) does not solve the problem since the resolution of the data is not improved compared to the HI surveys.

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Discussion : FREEDMAN.

ZINNECKER :

You showed that the radial distribution of the integrated blue light in M33 is very similar to the radial distribution of the young stars, and from this you concluded that the star formation rate hasn't changed since about 1 Gyr ago. I think your conclusion depends somewhat on what fraction the young stars alone contribute to the total blue light. Can you estimate their percentage?

FREEDMAN :

What you say is very true, the conclusion depends strongly on the shape of the IMF adopted, upper and lower mass cutoffs, and the star formation role as a function of time. The point that I meant to illustrate however, was that contrary to some previous studies which assumed that all of the blue light is due to young stars, for a "standard" (Salpeter) IMF with a slowly decreasing star formation rate, about half of the blue light comes from stars up to a few times 10^9 years.

MASSEY :

What magnitude range does your luminosity function cover (answer : 4). Over that sort of range, all that the constancy of the luminosity function in V means is that the exponent of the IMF does not vary by 3 or so (see my PASP 97,5 figure). Differences such as that suggested by Garmany et al. would go completly undetected in a luminosity function, even in V.

FREEDMAN :

The uncertainty in the sensitivity of the slope of the mass function derived from luminosity functions depends on the accuracy of the measured luminosity function. Thus, in order to detect changes in the slope of the mass function, at the level suggested by Garmany et al., the original sample of stars must be complete, otherwise, as you point out, small differences or errors in the luminosity function will be magnified in the mass function determination. As discussed by Scalo, and also by Humphreys and McElroy (1984, Apj 284, 565), the Galactic catalogues appear to be incomplete. Their analysis suggests that, within the uncertainties, no trend of the slope with radius is evident in the Galaxy.

In other words, as you suggest, very small changes (or errors) in the luminosity function will give rise to much larger changes (or errors) in the mass function.

KAUFMAN :

In M33 the radial distribution of the number of HII regions of all luminosities agrees with the blue light distribution; however the radial distribution of giant radio HII regions is much more sharply peaked than the overall distribution of blue light.

FREEDMAN :

Yes, that is correct. But if one compares either the number distribution or the flux from all HII regions, the radial distributions as compared to the stars are very similar. I am not quite sure how to interpret the steeper distribution of bright HII regions. It is difficult to rule out a selection effect of finding faint HII regions toward the center. There will also be a crowding problem due to the higher surface density of HII regions toward the center. Some bright HII regions may actually be aggregates of several smaller HII regions.

MOFFAT :

You stated that the ILF slopes at the bright end are constant for many different galaxies. Can you give us a more quantitative estimate of the slope and the slope of the more fundamental IMF (and their variations)?

FREEDMAN :

The slope of the upper end of the luminosity function for blue stars is about 0.7 ± 0.1. Scalo (see review of this volume) has tabulated the slope of the IMF for the present and several other recent determinations.