DWARF CONTENT OF OLD GALAXY POPULATIONS

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Abstract.* Scanner observations of five galaxies in the region near 9910 Å showed that the strength of the dwarf-sensitive Wing-Ford band is below the level of detection. This result is at variance with the predictions of strongly dwarf-enriched population models and in accord with the evidence for giant-dominated radiation at 2.3μ reported by Baldwin *et al.* (1973) on the basis of the strong CO band found in three galaxies. In the absence of any evidence for a power-law mass function, the consequences of a rounded function are examined.

A cool M-star component in the stellar population of elliptical galaxies and the central regions of Sb spirals is required by the strong infrared radiation found in wide-range spectrophotometric studies (e.g. Stebbins and Whitford, 1948; Johnson, 1966). Spinrad and Taylor's (1971; hereafter ST) population models for the nuclear regions of M31 and M81, based on extensive scanner measurements of the continuum and spectral features, identified this cool component with a dwarf-enriched lower main sequence. Observational evidence came mainly from the dwarf-sensitive Na feature at $\lambda\lambda$8183–8195. The more luminous E galaxies and the central regions of the more luminous Sb's form a homogeneous group with similar colours and strong spectral features (Faber, 1972).

The unidentified molecular feature at about 9910 Å, first noted by Wing and Ford (1969) in the spectra of late dwarfs, comes at a wavelength where the cool M-star component contributes a larger fraction of the total light relative to the giant K0 III component dominant in the violet (Morgan and Mayall, 1957). ST's model calculations show that contribution of the M stars is 22% at 8190 Å, 33% at 9910 Å, and 47% at 2.3μ. The preliminary scanner investigation of the strength of the Wing-Ford band (Whitford, 1972) has been extended to include 35 K and M stars, reaching dwarfs as late as dM8. The luminosity discrimination is found to increase with advancing type and to provide strong differentiation for types M5 and later.

No detectable indication of a dwarf population could be found from scanner measurements of the strength of the Wing-Ford band in 5 galaxies: the nuclear regions of the Sb spirals M31 and M81, and the ellipticals M32, NGC 4472, and NGC 4486. This result is in accord with the observations of Baldwin *et al.* (1973), who found that the giant-sensitive CO band at 2.3μ appeared at full strength in the nuclear regions of M31 and M81.

ST's scanner detection of the Na feature at a level well above the range of observational uncertainty stands in opposition to the results at longer wavelengths. Additional observations by a technique that eliminates the need to calibrate out competing side-band effects are desirable. A re-examination of the failure to find the Na doublet on

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photographic spectra of galaxies at 200 Å mm^{-1} (Whitford, 1966) showed that the line strength to be expected from the ST dwarf-enriched model for M31 would have been below the detection limit. Equivalent widths of the Na lines were determined on stellar spectra taken at 32 Å mm^{-1} for this analysis.

Table I shows a comparison of the average observed index $\Delta(9916)$ for galaxies and the indices predicted by population models. The index, which measures the absorption in magnitudes in a 32 Å scanner band, had observational mean error of ± 0.008 for M31, ± 0.010 for M81, and ± 0.024 for NGC 4472 and NGC 4486.

TABLE I

Model predictions

Galaxy	Model	M-star Component	$\mathfrak{M}/L_V$	$\Delta(9916)$
M31	ST	$\mathfrak{M}^{-3.6}$ to $\mathfrak{M}=0.1$	43.5	0.054
M81	ST	M stars partly giants	27	0.038
NGC 3379	ST	rounded at $\mathfrak{M}=0.15$	33	0.033
M31	mod. ST	$\mathfrak{M}^{-3.0}$ to $\mathfrak{M}=0.1$	13	0.027
M31	mod. ST	$\mathfrak{M}^{-2.0}$ to $\mathfrak{M}=0.1$	2.4	0.018
M31	mod. ST	M stars all giants	0.8	0.017
Mean observed index, 5 galaxies				0.012

Notes: M stars in models all dwarfs except as noted. ST: Spinrad-Taylor model as published. Mod. ST: Modified ST model.

The contradiction between the observations and the ST model for M31 must be considered in the light of the current downward revision of $\mathfrak{M}/L$ values of galaxies. Adoption of the new value for the velocity dispersions in the nuclear region of M31 found by Morton and Thuan (1973) would lower the ratio from $\mathfrak{M}/L_v=43.5$ to $\mathfrak{M}/L_v=13$. New observations of velocity dispersion in ellipticals (Morton and Chevalier, 1973) have not included the giant E's here considered. Existing dispersion data and results on E galaxies from the Page (1961) double-galaxy method suggest that for the giant E's $15<\mathfrak{M}/L_v<30$, assuming $H=50$ km s^{-1} Mpc^{-1}.

The table shows that a modified M31 model based on a power-law mass function that combines a satisfactory value of $\mathfrak{M}/L$ and a predicted $\Delta(9916)$ index compatible with observations is difficult, but perhaps marginally possible. Only a modest reduction in the exponent in the mass function $N(\mathfrak{M}) \propto \mathfrak{M}^{-x}$ from the high value $x=3.6$ in the ST model is possible if all mass is assumed to be in the form of stars.

If a high proportion of late dwarfs is no longer required to satisfy the observed spectral features, however, there would appear to be grounds for questioning the power-law mass function. There is no obvious physical process that would suddenly stop fragmentation at some particular low-mass cut-off. $\mathfrak{M}/\mathfrak{M}_\odot=0.1$ was adopted in the ST model. Kumar (1972) has pointed out that the known stars near the Sun of mass $\mathfrak{M}/\mathfrak{M}_\odot<0.08$, even though destined after a short life to become black dwarfs, could be significant in the mass budget of the solar neighbourhood. The crowding of the

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mass into the stars nearest the cut-off in a 'sawtooth' power-law mass function appears artificial. In the ST model for M31, the M8V stars at $\mathfrak{M}/\mathfrak{M}_\odot = 0.1$ represent 67% of the mass.

Larson (1973) has proposed a probabilistic fragmentation theory that results in a gaussian mass-distribution function $\theta(\mathfrak{M}) = \mathfrak{M}N(\mathfrak{M})$. In the solar neighbourhood the stars contributing the greatest mass per unit interval of $\log\mathfrak{M}$ are those near $\mathfrak{M}/\mathfrak{M}_\odot = 1.4$, and the observed rounding off at low masses (e.g. Hartmann, 1970) finds a natural explanation. The reduced proportion of M5–M8 dwarfs, relative to a power-law mass function, would yield a $\mathfrak{M}/L$ ratio too low for the type of galaxies here considered.

Larson has pointed out that, under the different conditions of star formation near the nucleus of a massive galaxy, the Jeans mass would be reduced and the peak of the mass distribution would be pushed toward a lower mass than that of the peak in the solar neighbourhood, thus increasing the fraction of the mass in lower main-sequence stars. The high mean density in the nuclear region would work in this direction. The shock waves mentioned by Larson as influencing the local density during initial collapse would presumably not be a major factor during the formation of the second-generation metal-rich stars that dominate the populations of massive galaxies. The absence of coolants in the metal-poor medium from which the first-generation stars formed during the initial collapse would favour a high proportion of short-lived supermassive stars, according to Truran and Cameron (1971). They suggest that these stars would leave a residue of black holes that would account for any missing mass.

Tinsley (1973) has interpreted the result from the CO band observations as pointing toward rapid luminosity evolution in old galaxy populations. If confirmed by similar observations of giant-E galaxies of the type used as test objects in the Hubble redshift plot, a correction Δq_0 to the apparent observed value of q_0 would result in a true value of q_0 near zero. Tinsley's analytical relation between x and the evolution rate applies particularly to the mass range $1 < \mathfrak{M}/\mathfrak{M}_\odot < 1.2$, i.e. to the stars at the main-sequence turnoff during the look-back time. The Wing-Ford band test is most sensitive to dwarfs of mass $0.1 < \mathfrak{M}/\mathfrak{M}_\odot < 0.2$, and the CO band appears to be most sensitive with respect to dwarfs of mass $\mathfrak{M}/\mathfrak{M}_\odot < 0.5$. In view of the quite significant changes in slope in Larson's (1973) physically plausible mass distribution model over a range $\Delta \log\mathfrak{M} \simeq 0.5$ to 0.7, there would appear to be some uncertainty in estimating the local slope of the mass function at the mass where the evolution rate is determined from observed upper limits to the numbers of stars of much lower mass, the M dwarfs.

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DISCUSSION

Van den Bergh: To how large an area do your observations of NGC 4472 and NGC 4486 refer?

Whitford: The scanner entrance aperture had the angular dimensions $12'' \times 60''$.

Larson: The results of some detailed galaxy evolution models computed by Beatrice Tinsley and myself (in preparation) show that the steep power-law mass spectrum proposed by Spinrad and Taylor is very difficult to reconcile with the various observed photometric properties of elliptical galaxies (*UBV* colours, etc.). The shallower Salpeter mass spectrum, and the gaussian mass spectrum which I suggested, both result in predicted colours which are in satisfactory agreement with observations. I think that our results are consistent with those of Dr Whitford.

Whitford: Yes, though I think there may still be trouble with the mass-luminosity ratio. It is of course possible to squeeze in a much larger mass for a given total light by assuming that the maximum of the Larson gaussian distribution function comes at an appropriately small fraction of the solar mass. One has to analyze whether a maximum consistent with the observed value of M/L will not at the same time predict so much light from low-mass dwarfs as to be inconsistent with the negative results from the dwarf-sensitive indicators. Black holes may turn out to be unavoidable.

E. M. Burbidge: Which are the crucial Spinrad-Taylor measurements giving the high M/L ratio – which ones ought to be rechecked?

Whitford: The greatest weight was given to the strength of the dwarf-sensitive Na 8190 feature. Sandra Faber has shown that the distribution of mass among the M dwarfs is not well determined by the Spinrad-Taylor observations of M31, and that a lower M/L value is not excluded. Their 32 Å scanner band included a significant amount of absorption by water vapour, subject to night-to-night variations. Giant-sensitive TiO absorption in the sidebands added a second complication that had to be allowed for. A check by a technique that isolated and measured only the strength of the Na doublet lines would be desirable.

G. de Vaucouleurs: Have you considered the possibility that strong infrared radiation like that observed from Seyfert galaxies could fill in the absorption in the Wing-Ford band expected from dwarf stars?

Whitford: I am not sure about the angular extent of the infrared sources in the Seyferts. The abnormal optical effects are confined to an area around the nucleus smaller than that accepted by the scanner. Johnson's infrared observations of ellipticals showed an energy curve falling off at 3.4μ in a way that was compatible with a reasonable M-star component, with no unexplained excess. In any case, a rather peculiar infrared source is required if it is to fill in the Wing-Ford band and leave the CO band at 2.3μ at full strength, as observed by Baldwin *et al.*

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