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INITIAL MASS FUNCTION IN STARBURST GALAXIES WITH DIFFERENT METALLICITY

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RESUMEN: Presentamos un análisis sobre la población estelar masiva en 8 galaxias de brote y en 4 galaxias azules compactas basado en los anchos equivalentes de las líneas p-cisne *UV* Si IVλ1400 A y CIVλ1550 A reportados (en parte) por Sekiguchi y Anderson (1987*a*, *b*). En base a este análisis estimamos también la temperatura efectiva ionizante promedio $\langle T_{*ioniz}\rangle$ y comparamos estos resultados con modelos de fotoionización. Nuestro método sugiere valores mayores ($\sim$ 8%) para $\langle T_{*ioniz}\rangle$. Estimamos la metalicidad en estos objetos utilizando diferentes métodos. Los modelos de fotoionización indican metalicidades mayores que las derivadas por los otros métodos. Encontramos que en los sistemas estelares de baja metalicidad, o bien hay una mayor proporción de estrellas masivas, o bien se alçanza un mayor límite superior para la función actual de masa. Esta última posibilidad parece proporcionar un mejor acuerdo con los modelos de fotoionización.

ABSTRACT: We present an analysis of the massive stellar population in 8 starburst galaxies and 4 blue compact galaxies based on the equivalent widths of the *UV* p-cygni lines Si IV λ1400 A and CIVλ1550 A reported (in part) by Sekiguchi and Anderson (1987*a*,*b*). These lines are characteristic of early OB stars and represent good indicators of the massive stellar content. Based on this analysis we estimate the mean ionizing effective temperature $\langle T_{*ioniz}\rangle$ and compare these results with photoionization models. Our method indicate larger values ($\sim$ 8%) for $\langle T_{*ioniz}\rangle$. We estimate the metallicities using different methods. The photoionization models indicate larger metallicities than those derived by the other methods. We also found that in the lower metallicity stellar systems there is a larger proportion of massive stars or a larger upper mass limit for the present day mass function. This second possibility seems to agree better with photoionization models.

Key Words: **STARS – MASS FUNCTION – GALAXIES-STARBURST**

I. INTRODUCTION

There are reports (contradictory in some cases) about possible radial variations of the initial mass function (IMF) in the solar neighborhood (Burki 1977; Boissé *et al.* 1981; Garmany *et al.* 1982). Radial excitation gradients at low metallicities ($10^4 \leq O/H \leq 4\times10^{-4}$) in spiral galaxies are the strongest evidence suggesting a gradient in the average effective temperature of the ionizing stars, wich in turn may be related to variations of IMF's parameters (slope α and/or upper mass limit m_{sup}) with galactocentric distance and perhaps with metallicity (Z). Some authors have suggested a dependence of either m_{sup} with Z ($m_{sup} \sim Z^{-A}$, with $A \leq 0.5$; Kahn 1974, Shields and Tinsley 1976, Panagia 1980), or α with Z ($\alpha \sim log$ (Z); Terlevich and Melnick 1981 and Terlevich 1985). In this paper we present an alternative method for estimating $\langle T_{*ioniz}\rangle$ using ratios of *UV* equivalent widths (sensitive to the massive stellar population), and discuss evidence suggesting variations of the upper present day mass function (PDMF) and its possible correlation with metallicity.

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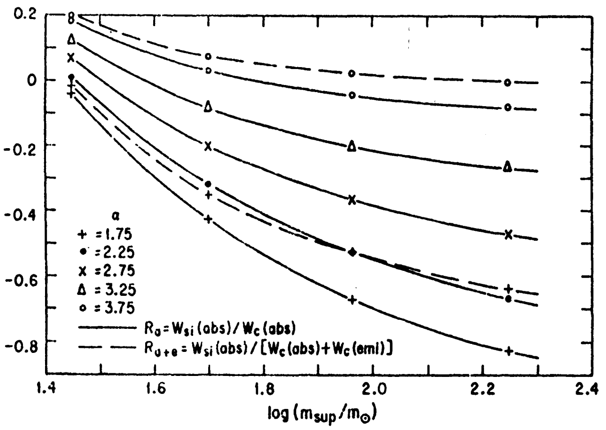
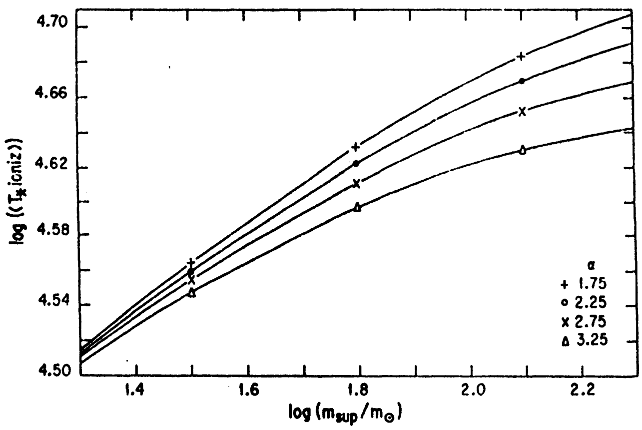
[. OBSERVATIONAL DATA

UV equivalent widths (EWs) in absorption and emission of the p-cygni lines Si IVλ1400 A and CIVλ1550 [denoted by W_{Si}(abs), W_C(abs) and W_C(emi)] for the 8 SBG were taken fro:n Sekiguchi and Anderson (1987*a,b* enceforth SA), while those for the 4 BCG were measured directly from spectra reported by Rosa *et al.* (1984, for [k33 and Mk35) and Fanelli *et al.* (1987, for Mk59 and Mk71). Observed optical spectral lines (needed to compute xygen abundances) for the 8 SBG, were compiled from the literature using references cited by Mazarella and Balzano [986). Optical spectral data for the remainig BCG were obtained with a Boller & Chivens spectrograph attached to ıe 2.1 m telescope at San Pedro Mártir Baja California, México. Resulting spectra were derreddened using Whitford's lassic extinction law, as given by Torres-Peimbert and Peimbert (1977). The logarithmic reddening correction $C(H_\beta)$ 'as derived using the (H_α/H_β) observed ratio.

[I. POPULATION SYNTHESIS AND METALLICITIES

Following the pioneering work of SA we calculated the synthesized EWs W_{Si}(abs), W_C(abs) and W_C(emi). [ain sequence (MS) stars in the solar neighborhood do not present the Si IV emission component. CIV lines ɔarticularly in emission) for MS stars are feature sensitive to spectral type (stellar mass) and enable us to use these .Ws as mass tracers. The observed Si IV emission component in the studied galaxies evidences the presence of giant nd supergiant populations. We estimated the relative contribution from different luminosity classes to the observed .Ws using the proportions of dwarfs, giants and supergiants for early type stars in the solar neighborhood given by ›isiacchi *et al.* (1979; approximated here by 0.7, 0.15 and 0.15 for classes V, III and I, respectively), together with "mean" EW (over spectral types) for each luminosity class derived using SA's empirical calibrations. We found that [S stars contribute with ~ 70% , 95% and 100% to the observed W_{Si}(abs), W_C(abs) and W_C(emi) respectively. We ssume that these *UV* features are dominated principally by the stellar atmospheres of the massive OB stars. We sed the modified observed EWs according to these fractions, assuming the same relative proportion in all galaxies ıdependently of their metallicity (hence these proportions actually constitute an upper limit for those metal poor alaxies). It would be desirable to calculate a particular proportion for each galaxy according to its metallicity and bserved EWs. Intrinsic continuum flux for the considered lines were estimated from the *UV* continua library reported y Wu *et al.* (1980), together with an intrinsic visual magnitude – spectral type calibration (Allen 1973). The PDMF 'as approximated by an IMF (dn/dm) ~ $m^{-\alpha}$ multiplied by a lifetime scale $\tau(m)$. The used lower limit is $m_{inf} \approx 6m_\odot$. Ve calculated the synthesized EWs as function of α and m_{sup}. We define the parameters $R_a = W_{Si}(\mathrm{abs})/W_C(\mathrm{abs})$, and $R_{a+e} = W_{Si}(\mathrm{abs})/[W_C(\mathrm{abs})+W_C(\mathrm{emi})]$ and show our theoretical results in a diagram $\log(R_a)$ or $\log(R_{a+e})$ versus $\log(m_{sup})$ ɔr constant α. See Figure 1 (with $\alpha_{Salpeter} = 2.35$). Using this graph and the "corrected" (MS stars only) R_a and R_{a+e} bserved values, we assigned to each galaxy both m_{sup} (for constant α) and α (for constant m_{sup}) values. Given the imilar behavior of R_a and R_{a+e} both with m_{sup} and with α, we could not assign a "unique" value of (m_{sup}, α) to each ;alaxy.





ig. 1. Theoretical relation between R_a or R_{a+e} and the upper mass limit m_{sup}, for constant IMF's slope α. See text.

ig. 2. Theoretical relation between the synthesized mean ionizing effective temperature $\langle T_{*ioniz}\rangle_{synth}$ (for $Z = Z_\odot$) and (m_{sup}, α).

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From the set of (m_{sup}, α) values, we assigned to each galaxy a synthesized mean ionizing effect temperature $\langle T_{*ioniz}\rangle_{synth}$ in the following way: using calibrations for stellar effective temperature $T_*(m)$ and for ioniz photon flux $N_c(m)$ for MS stars and solar abundance as function of mass, we constructed theoretical relations betw $\langle T_{*ioniz}\rangle_{synth}$ and (m_{sup}, α), shown in Figure 2, that permit to assign a $\langle T_{*ioniz}\rangle_{synth}$ value if (m_{sup}, α) is known. The T_* and $N_c(m)$ relations were adapted from Avedisova (1979) and Schmidt-Kaler (1982). Additionally, we consider intrinsic relation between $T_*(m)$ and metallicity: $\Delta \log(T_*) \approx -0.03 \times \Delta \log(Z/Z_\odot)$, deduced from Brunish and Trura (1982) models.

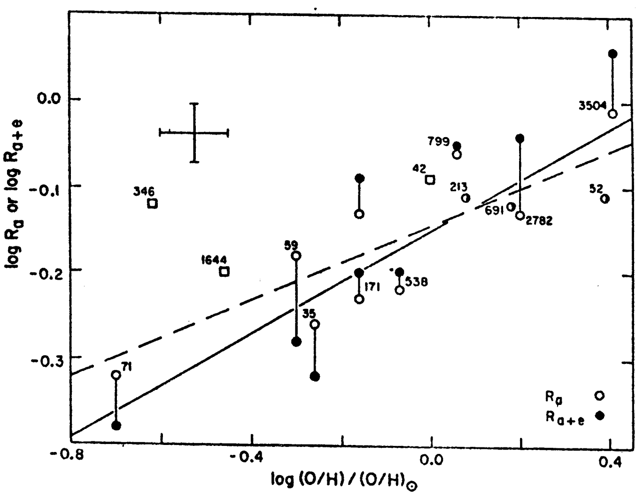
a) Metallicities and Mean Ionizing Effective Temperatures

Electron temperatures T_e were estimated from: a) the [O III]λ4363 line (for 5 galaxies; Aller 198 b) Alloin *et al.'s* (1979) calibration; c) Pagel *et al.'s* (1979) calibration and d) Stasinska's (1980) models. A reasona agreement (~ ±800K) is found among different estimates. Electron densities n_e were calculated from the classic sulp lines (for 6 galaxies; Aller 1984 and McCall 1984); $n_e \approx 300 cm^{-3}$ was arbitrarily assigned for the remaining galaxi Ion abundances, X^{+m}/H^+, were calculated through the expression:

$$\log[X^{+m}/H^+] = \log\{f_{X^{+m}}[\log(T_e), \log(x)]\} + \log\{I(\lambda, X^{+m})/I(H_\beta)\}$$

where $x = 0.01(n_e/cm^{-3})(T_e/K)^{-1/2}$; $f_{X^{+m}}(\log T_e, \log x)$ is a function depending on atomic parameters of the given i X^{+m} and $I(\lambda, X^{+m})$ is the dereddened line intensity at λ of the X^{+m} ion (λ = [O II], [O III] for O^+, O^{+2}). The f_X functions for O^+ and O^{+2} were constructed based on Aller (1984). These graphs (available from the authors) may be interest for people working on nebular chemical abundances. Total oxygen abundances were approximated by (Al 1984): $O/H \approx (O^+ + O^{+2})/H^+$. The resulting total abundances have an estimated error of a factor of 2.

As indirect methods we tried: a) Edmunds and Pagel's (1984) semi-empirical calibrations; b) a H_α/ II] λ 6584 vs. (O/H) diagram adapted from data on BCG reported by Kunth and Joubert (1985), c) vario "diagnostic diagrams" constructed from Stasinska's (1982) models, and d) McCall *et al.'s* (1985) and Dopita and Eva (1986) models. There is general agreement among the different estimates, the deviations fall within the estimat uncertainties. Adopted abundances take into account all methods, giving more weight to the "atomic paramete method, because of its higher reliability. Relative abundances among different galaxies calculated with a given meth are similar for all methods. The $\langle T_{*ioniz}\rangle$ values were estimated using Stasinska's (1982) models, complemented by the of McCall *et al.* (1985). Both methods give analogous relative temperatures over the sample.



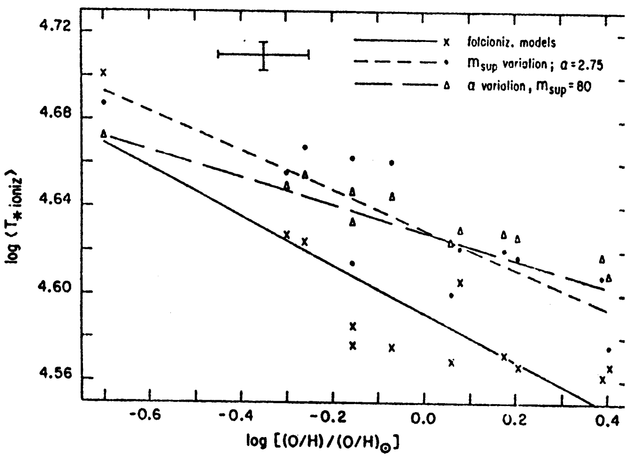


Fig. 3. Observed relation between R_a (dashed line) or R_{a+e} (solid line) and metallicity. Plotted galaxies are Mk33, 35, 59, 71; Mk 52, 171, 21 538, 691, 799, NGC2782, 3504; plus 3 H II regions: M42 (Orion), NGC 346 and IC 1644. See text. Here $(O/H)_\odot = (O/H)_{Orion} = 4.467$ 10^{-4} (Peimbert *et al.* 1986). Correlation coeficient C = 0.83. Cross indicates typical uncertainty.

Fig. 4. Derived relation between mean ionizing effective temperature ($\langle T_{*ioniz}\rangle$ - through photoionization models; ($\langle T_{*ioniz}\rangle_{synth}$ - throug *UV* EWs) and metallicity. Cross indicates typical uncertainty. Plotted galaxies as in Figure 3.

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IV. RESULTS AND DISCUSSION

The main trend found in this paper, shown in Figure 3, is the R_a (and R_{a+e}) – Z relation, which may be showing a $m_{sup}(Z)$ dependence in a quasi–stationary burst of star formation. In Figures 5*a* and 5*b* we present the assigned set of (m_{sup}, α) values and the metallicity to each galaxy. Two of the linear regressions in those figures yield:

$$(m_{sup}/m_{\odot}) \approx 80(\pm 5) \times (Z/Z_{\odot})^{-0.45(\pm 0.05)}, \text{ for } \alpha = 2.75 \quad , \tag{2}$$

$$(\alpha) \approx 2.70(\pm 0.20) \times (Z/Z_{\odot})^{+0.15(\pm 0.05)}, \text{ for } m_{sup} = 80 m_{\odot} \quad . \tag{3}$$

With weak correlation coeficients ~ 0.84 and 0.77 respectively; $\alpha = 2.75$ is approximately the mean α value over the sample for $m_{sup} = 80 m_{\odot}$; $m_{sup} = 80\ m_{\odot}$ (maybe higher) is the m_{sup} value giving α values in better accordance with derived ones for similar systems ($\alpha \approx 2.5 \pm 0.5$, Scalo 1986). The average $|\alpha|$ is smaller (~ 0.15) than the value for the massive ($m \geq 15 m_{\odot}$) IMF in the solar neighborhood recently derived by Vereshchagin (1988; $\alpha_{\odot} \approx 2.85$), favouring a massive stellar population in these systems. This is also supported by the $W(H_{\beta}) \geq 20$ A observed for 8 of the galaxies.

In Figure 4 we compare the resulting relation between the assigned $\langle T_{*ionz}\rangle_{synth}$ (for $\alpha = 2.75$ or $m_{sup} = 80 m_{\odot}$) with Z for each galaxy, with the relation $\langle T_{*ioniz}\rangle$ versus Z found employing photoionization models. Apparently the (noisy) slope of the $\langle T_{*ioniz}\rangle$ vs Z relation (derived through photoionization models) is better reproduced if there is m_{sup} that varies with Z instead of an α variation. Figure 4 also suggests that a) the $\langle T_{*ioniz}\rangle$ values are underestimated, b) our m_{sup} values are somewhat overestimated or c) our α values are underestimated. Considering a larger proportion of MS stars in the observed R_a and R_{a+e} parameters, would produce a bigger $|\alpha|$ value ($\Delta\alpha \sim 0.3$ to 0.5) or equivalently, a smaller upper mass limit ($\Delta m_{sup} \sim 5$ to $15 m_{\odot}$).

Correlations shown in Figure 3 (and hence in Figures 5a and 5b) may be explained in different ways: a) It could be an evolutionary effect causing the R_a and R_{a+e} parameters to increase as an instantaneous (~ 10^6 years) burst of star formation evolves, producing a diminishing relative fraction of massive stars while metallicity increase. However, considering the observed $R_a(Z_{\odot})$ values and SA's empirical calibrations, we are tempted to conclude that the SM contamination is insufficient to explain the observed Z; b) There could be an intrinsic dependence of the R_a and R_{a+e} parameters on Z. In this case the observed $R_a(Z)$ relation may be stronger, because, as Si is mainly produced by type II SN and C is produced principally by intermediate mass stars, it would produce an enhanced relative abundance ratio Si/C in poor metal systems. However, the tendency of Si to form dust grains may tend to neutralize this effect; c) Effects on the stellar structure (wind activity) due to different Z and d) The m_{sup} (or α) of the PDMF may vary with Z in a quasi–stationary (~ 10^6 to 10^7years) burst of star formation, showing the possible influences that the environment may have over the processes of star formation, particularly for massive stars. The relatively high upper mass limit attained in some galaxies (~ 100 to $200 m_{\odot}$ in Mk71 and Mk59), may correspond to the reduced cosmic dust–to–gas ratio needed to form these massive stars suggested by Wolfire and Cassinelli (1987). Previous studies on similar systems (e.g. Scalo 1986 and references therein), also indicate that they are relatively deficient in low mass stars. Further studies of extended optical and *UV* sample data will certainly shed more light on these fundamental problems.

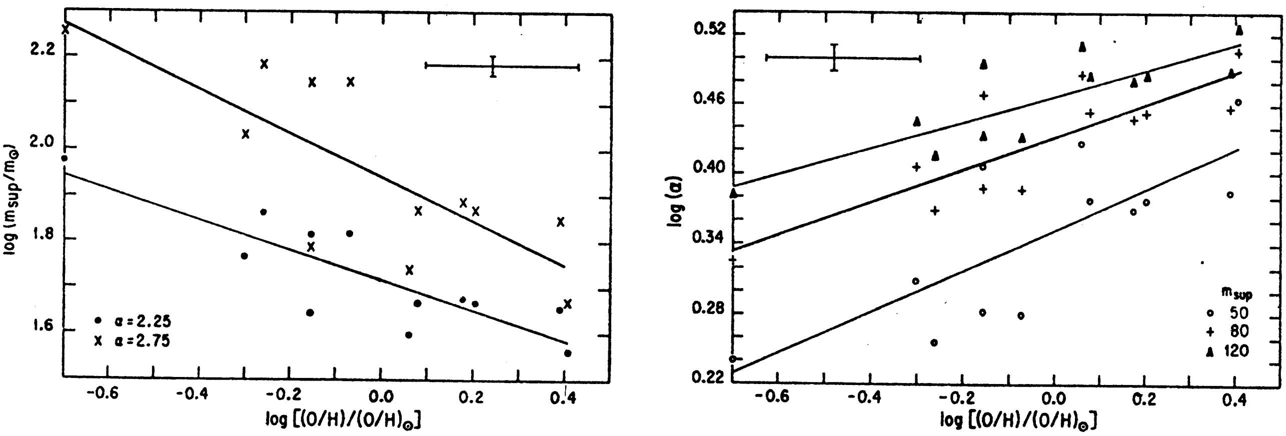

Fig. 5a (and 5b). Derived relation between assigned upper mass limit m_{sup}, at constant α (and assigned slope α, at constant m_{sup}) and metallicity. Cross indicates typical uncertainty.

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