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The Dwarf Blue Compact Galaxies

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1. Introduction

Among the very different types of galaxies which can be analysed, the dwarf blue compact galaxies have been first recognized as a class by Sargent and Searle (1970: *Astrophysical Journal*, **162,** 455). Some important properties let them be priceless tools to enlighten many basic astrophysical problems, such as the primordial nucleosynthesis and cosmology, the chemical evolution of galaxies and the theories of star formation. These galaxies are generally dwarf irregular objects with low mass but the bulk of the luminosity is in the blue range. Their spectra look strikingly like those of a giant H II region. That is why they have been called extragalactic H II region by Sargent and Searle. From their emission lines it is rather straightforward to derive their He, N, O, Ne and possibly S content. Some of these abundances, including some of our own results obtained at La Silla, are summarized in Section 3.

Finally we will show the most important implications of results deduced from the study of these galaxies:

(i) Their weak metallicity can be correlated with their high atomic hydrogen content and their blue luminosity. These objects are especially important for galactic evolution models, because they appear to be much less evolved galaxies than ours and because they also show obvious signs of recent bursts of star formation.

(ii) From the comparison between their helium and their metal content we can deduce the primordial abundance in helium. This is one of the basic parameters to select among the many possible cosmological models describing the early phases of the Universe. Moreover and within the canonical Big Bang model it could provide some insight on a few characteristics of the physics of elementary particles, such as the number of different classes of not yet observed leptons.

2. The Morphology of the Blue Compact Galaxies

Two recent kinds of surveys have been performed. One of spectroscopic nature by Kunth and Sargent (1979: *Astronomy and Astrophysics Suppl.*, **36,** 259; 1980: ESO preprint no. 99) and a photographic one by Barbieri et al. (1979: *Astronomy and Astrophysics Suppl.*, **37,** 541).

These objects, which do not seem to belong to a specific category of the Hubble classification (there are a few elliptical-like galaxies which can be considered as blue compact objects), are mainly characterized by their relatively small size – the size of the emitting region is only a fraction of a kpc. They show strong emission lines (see e.g. a typical spectrum of Tol 116 in Fig. 1) and have quite a faint absolute visual magnitude

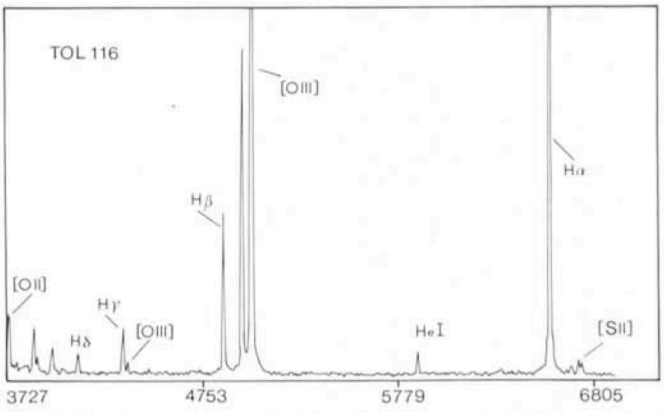

Fig. 1: *This is a spectrum of Tololo 116 taken by J. Audouze and M. Dennefeld at La Silla with the IDS at the Cassegrain focus of the 3.6 m telescope.*

($M_V \geqslant -17$). Their colour indices U-B and B-V range respectively between -0.4 and -0.75 and 0.4 and 0.0.

The total mass of these objects can be estimated by the classical (but not very accurate) method of the velocity dispersions. For instance in the case of I Zw 129 and II Zw 70, O'Connell and Kraft (1972: *Astrophysical Journal*, **175**, 335) found quite low velocity dispersions (25–30 km/s), no evidence for unusual gas motion and deduced masses of the order of a few $10^9 M_\odot$.

These galaxies have been thoroughly analysed in 21 cm (see for instance Balkowski et al. 1978: *Astronomy and Astrophysics*, **69**, 263). Their gas content compared to their total mass can be as high as 0.22 in the case of II Zw 70. They really appear to be among the most gas rich galaxies. A careful mapping of II Zw 70–71 revealed that these two galaxies form an interacting system. By combining infrared with radio observations Jaffe et al. (1978: *Astrophysical Journal*, **224**, 808) seem to propose that II Zw 40 has a gas/dust ratio similar to that of our galaxy. This type of conclusion is a bit surprising when one considers the apparent low metallicity of these objects.

To summarize, although their optical morphology is fairly heterogeneous, a large fraction of these galaxies are among the lightest, the most irregular and bluest galaxies. Their irregularity and small mass suggest that they should be *a priori* less affected by dynamical effects, such as spiral structure, and should accrete very little extragalactic material. We also point out that up to now there is no clear evidence of an underlying stellar old population which would have a direct implication on the nature of these objects (see Section 4.2).

3. The Composition of the Blue Compact Galaxies

The analyses of the composition of these rather unevolved galaxies are performed in the same way as those of the HII regions. We have observed such objects ourselves, like Mark 750, CPG 217 and Tololo 116, by using the ESO 3.6 m telescope on La Silla, equipped with the Boller and Chivens spectrograph and the Image Dissector Scanner. From the [O III] lines one can deduce the temperature of the emitting gas, which is about 10^4K, while the electron density, as deduced from the [S II] lines, amounts to a few hundred electrons cm^{-3}. The ionized mass is of the order of $10^6 M_\odot$.

Since the problem of line transfer is not crucial, the derivation of cosmic abundances from observed intensities is straightforward. The major problem in giving the final abundances is the correction made to account for unseen ionization stages.

From various authors one may stress that the metal content of these objects is strikingly deficient as compared to the Standard Abundances.

In the case of I Zw 18 the O/H deficiency is as high as 37. The less deficient objects show underabundances by factors of about 3. The same trend is observed for Ne, N and S and also the helium content, which make these objects suitable for a discussion of the primordial helium.

Notice that the abundances of Magellanic type irregular galaxies (LMC, SMC, NGC, 6822) are within the range of abundances found for these compact galaxies, although never so extreme.

4. Astrophysical Implications

The implications of these observations concern:

(i) the evolution of these objects. In this respect one would like to know if they underwent bursts of stellar formation, when these bursts occurred and what triggered them.

(ii) the primordial helium content.

4.1. Chemical Evolution of the Blue Compact Galaxies

Because of the high gaseous content and the low metallicities of blue compact galaxies, it is important to analyse the evolution of these objects, which is fairly easily accounted for, theoretically.

As noted by Audouze and Tinsley (1976: *Annual Review of Astronomy and Astrophysics*, **14**, 43), when the gas content is still high, the so-called Instant Recycling Approximation holds, i.e. one can neglect the lifetime of the stars with respect to the evolution time scale of the system, the relations describing the evolution of the gas density and the metallicity can be solved algebraically. In particular, one can define the yield of metal production, i.e. the amount of metal produced per unit of mass locked into stars.

In the so-called "simple models" where this approximation is made, the relation between the metallicity Z, the gas content and the yield p is $Z = p \ln (M_{tot}/M_{gas})$.

This relation has been well verified in the case of the sample studied by Lequeux et al. (1979: *Astronomy and Astrophysics*, **80**, 155). With a linear least square fit on their data they find:

$$Z = (-0.03 \pm 0.16)\ 10^{-2} + (3.9 \pm 0.10)\ 10^{-3} \ln \frac{M_{tot}}{M_{gas}}$$

which means that the yield in blue compact galaxies is $\sim 10^{-3}$. This implies that the primordial metallicity for these galaxies might have been zero and that the value of the yield deduced from this relation is therefore quite consistent with the values deduced by Pagel (1978: *Monthly Notices of the Royal Astronomical Society*, **183**, 18) and Pagel and Patchett (1975: *M. N. R. A. S.*, **172**, 13) for the solar neighbourhood ($p = 5 \pm 1\ 10^{-3}$). This yield can only be reproduced in models of chemical evolution if one takes into account important stellar mass loss effects (Chiosi and Caimmi, 1979: *Astronomy and Astrophysics*, **80**, 234): theoretical models lead to yields as high as $1.3\ 10^{-2}$ without mass loss and $2\ 10^{-4}$ to 10^{-3} with mass losses. The mass loss processes, which might be related to the blue colour of these objects and to their high ionization rates, are necessary to account for their evolution.

One can notice also that there may be a relation between the total mass of the galaxies and their metallicity. According to Lequeux et al.: $\mathrm{Log}\ M_{Tot} = 8.18 + 230\ Z$ where M_{Tot} is expressed in solar masses. We believe that this relation is just an indicative trend, the lower limit of $10^8 M_\odot$ should be considered with much caution.

Finally, the Ne/O ratio is normal, which means that Ne is as primary as O. By contrast, N/O is about twice as small in these galaxies as it is for Orion or the Sun. The scatter of the observed N/O ratios, however, clearly indicates that N is neither purely primary nor purely secondary; this conclusion would agree with the findings of Alloin et al. (1979: *Astronomy and Astrophysics*, **78**, 200) from HII regions observed in spirals.

4.2. Stellar Bursts in Blue Compact Galaxies

The blue colour of these objects is due to a presently intense rate of star formation. The concept of burst seems to apply very well to this class of galaxies, since their low metallicity indicates that the present rate of star formation exceeds much the average rate in the past. The basic question (which may be a pure semantic one) is to know whether these galaxies are young and experience their first burst, or if these objects are old, have already formed stars and are just suffering a new burst.

This question has not yet received convincing answers. Searle and Sargent (1972: *Astrophysical Journal*, **173**, 25), on statistical grounds, argued that these galaxies must be old.

However, Lequeux and Viallefond (1981: *Astronomy and Astrophysics*, in press) have been able to investigate this problem in the case of I Zw 18. For this object, they compare the luminosity due to ionizing Lyman continuum photons, the far UV flux around 1700 Å, which is mainly due to the B0,B5 stars, the blue luminosity and the abundance of oxygen. By using current models of chemical evolution of galaxies, such as those which describe the evolution of their luminosity, they show that the luminosity in the Lyman continuum and the luminosity in the far UV evolve differently with time. The Lyman continuum luminosity depends on more massive stars than the far UV and the visible luminosity. From the observed properties of I Zw 18 they argue that a recent burst of duration 4-6 10^6 years might be responsible for the major part of the observed oxygen. They would conclude that I Zw 18, which appears to be formed of about six debris interacting gravitationally, is just starting its first burst of star formation.

Tentative Time-table of Council Sessions and Committee Meetings in 1981

May 4	Committee of Council
May 7–8	Finance Committee
May 7	Scientific Technical Committee
May 8	Users Committee
May 21–22	Observing Programmes Committee
June 4	Council, Stockholm
November 10	Scientific Technical Committee
November 11–12	Finance Committee
November 13	Committee of Council
Nov. 30–Dec. 1–2	Observing Programmes Committee
December 3–4	Council

All meetings will take place at ESO in Garching, unless stated otherwise.

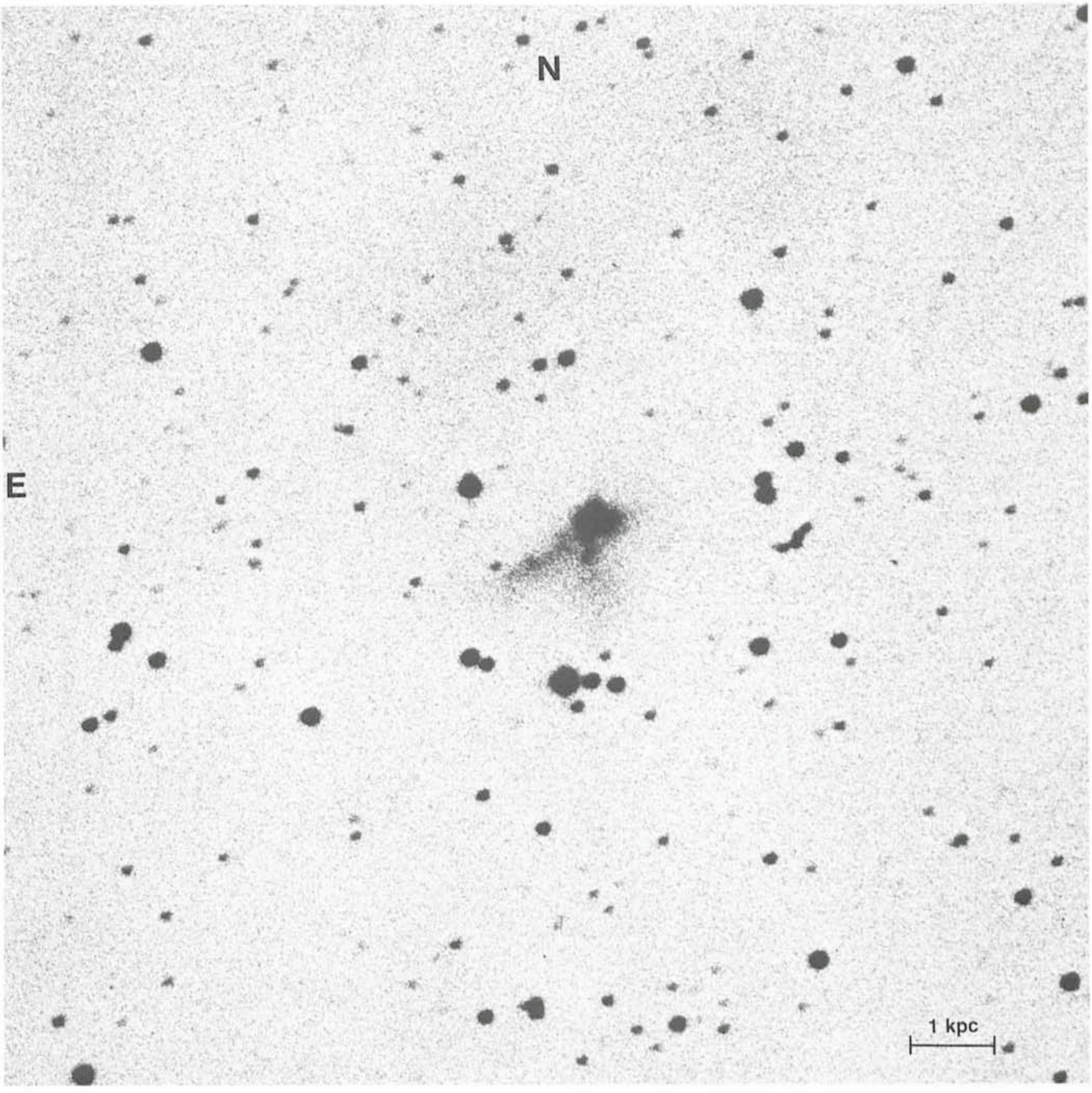

Fig. 2: *This is a blue picture of II Zw 40 taken at the prime focus of the 5 m telescope at Palomar and lent to D. Kunth by W. L. W. Sargent. North-East is at the top left corner. The scale shows the distance in kiloparsec.*

This conclusion may apply only to I Zw 18 among the known compact galaxies. Lequeux and Viallefond would propose that other galaxies, such as II Zw 70–71, which are more complex, rotating, and which have had time to become relaxed systems, are older than I Zw 18.

4.3. The Primordial Helium Abundance

Let us denote by Y the fractional helium abundance by mass. A comparison between the helium and the metal content implies that the corresponding galactic enrichments ΔY and ΔZ are proportional: $\Delta Y = \alpha \Delta Z$ with $\alpha \approx 3$. Again such a high value for α can only be reproduced in models of chemical evolution involving important stellar mass loss. Without mass loss, the α coefficient would only be at most 0.5 to 0.1. This can be easily understood if one recalls that helium can be reproduced by low-mass stars, while in massive stars the metal enrichment increases more than the helium enrichment.

Recent studies have been devoted to the determination of the primordial helium abundance by extrapolating Y to $Z = 0$. Lequeux et al. (1979: *Astronomy and Astrophysics,* **80,** 155) and, more recently, Kunth and Sargent (1981: in preparation), on a wider sample of blue compact galaxies, have discussed this relation (Y, Z), out of which the "primordial" value seems to converge to about $Y_p = 0.235 \pm 0.010$ with the value quoted above, and by adopting the canonical[1] Big Bang theory to account for the early phases of the Universe, one can deduce an upper limit for the present density of the Universe $\varrho \leqslant$ 3–5 10^{-31} g cm^{-2} (see e.g. Yang et al. 1979: *Astrophysical Journal,* **227,** 697).

Therefore, the Universe is expanding for ever (it is open!); the primordial nucleosynthesis is able to account for the observed abundances of deuterium. Moreover, it provides a quite strict limit on the number of possible different families of leptons, which should be $\leqslant 3$. If the discovery of the tau lepton is confirmed, one should not find any new type of leptons unless the canonical Big Bang models do not apply. From such conclusions, the observations of the blue compact galaxies are of prime importance in cosmology.

5. Conclusion

Significant progress has been made on this class of quite unevolved galaxies.

(i) their primordial content of helium now seems to be well established $Y = 0.233$ and is consistent with an open Universe, a canonical Big Bang model and no unknown type of leptons.

(ii) The helium over metal enrichment is about 3 and seems to indicate that the stellar mass loss plays an important role in fixing this ratio at this value.

(iii) The blue compact galaxies are quite unevolved: one galaxy, I Zw 18, has an oxygen abundance about 40 times lower than the solar value. They are well described by the simple models with instant recycling approximation. This means that their primordial metallicity might have been equal to zero. The value of the yield, deduced from the comparison of the metallicity with the gas content, implies that stellar mass losses should operate. Moreover, there is a correlation between the metallicity and the total mass of these galaxies, for which nitrogen appears to be partially secondary.

(iv) These objects have very different morphological aspects although they have rather low masses, high intrinsic luminosities, conspicuous hot H II regions and blue colours. Some of them are isolated, while a few others, like II Zw 70, belong to interactive systems. One of the most intriguing object is I Zw 18, which seems to be made of several interacting debris which have just experienced a very recent burst of star formation. The differences between some of the blue compact galaxies might come from the time when the bursts of star formation occurred.

The advent of forthcoming UV missions, like the space telescope or the post IUE projects, will obviously reveal more characteristics of these very important galaxies: their actual nature and why their rate of star formation is sudden rather than continuous. It would allow better determinations of mass loss effects, and measurements of the composition in carbon. As it has been seen for I Zw 18, the far UV luminosity provides some information on the occurrence of the stellar bursts. Moreover, if (as it is expected in UV projects like Magellan) the 900–1100 Å wavelength is observable, a direct measurement of the deuterium abundance in such unevolved objects would be of utmost interest for cosmological models.

[1] In such models one assumes that:
(i) the early Universe was homogeneous and isotropic,
(ii) there was no significant amount of antimatter,
(iii) General Relativity accounts well for the gravitational interactions,
(iv) the leptons are non degenerated,
(v) there were no unknown elementary particles, and
(vi) the early phases of the Universe were dense and hot ($T > 10^{11}$ K)

PERSONNEL MOVEMENTS

STAFF

ARRIVALS

Europe

VÖLK, Elisabeth, D, Secretary, 1.11.1980
GUSTAFSSON, Karl, S, Analyst/Programmer, 1.1.1981
HESS, Guy, F, Designer/Draughtsman, 1.1.1981
POMAROLI, Edouard, F, Electro-mechanician, 1.1.1981

DEPARTURES

Europe

ANDERSSON, Sölve, S, Electronics Technician, 31.12.1980

Chile

VOGT, Nikolaus, D, Astronomer, 30.11.1980

ASSOCIATES

ARRIVALS

Chile

NISSEN, Poul, DK, 1.2–31.7.1981

FELLOWS

ARRIVALS

Europe

BAADE, Dietrich, D, 1.2.1981
BENVENUTI, Piero, I, 1.2.1981
KRUSZEWSKI, Andrzej, Poland, 1.2.1981

DEPARTURES

Europe

MELNICK, Jorge, Chile, 28.2.1981

COOPERANTS

ARRIVALS

Chile

ANGEBAULT, Louis, F, Coopérant, 29.10.1980