# АСТРОФИЗИКА

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## THE IMPORTANCE OF BLUE COMPACT GALAXIES

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I review the importance of blue compact galaxies with respect to current studies of massive star formation, abundances of elemental and heavy elements in the interestellar medium and to the epoch of galaxy formation. Their relevance to cosmological studies will be emphasized.

1. *Historical comments.* Around the 60's astronomers, both observers and theoreticians were discussing the problem of galaxy formation with sometimes quite drastic opposite points of view. In Armenia, Professor V.A.Ambartsumian had envisioned the view that galaxy nuclei generate from explosive events while in the US a picture involving gravitational collapse from primordial HI clouds was prefered. F.Zwicky following a distinct line of thinking and unlike E.Hubble soon argued that dwarf galaxies would be the dominant population in the Universe. He furthermore speculated tha. at their ultimate stage cosmological entities would evolve into highly concentrated densities as it was indeed found with neutron stars. At larger scale, he envisioned that galaxies with high stellar densities, that he named "compact galaxies" should also be found.

It is interesting to note what regardless their predictive pertinence, these leading views have been quite fruitful for the development of science and led to numerous studies of a large variety of new class of galaxies hence opening new areas of research. This appears to be true for AGN studies, and as well for the discovery and follow up studies of blue compact galaxies. In particular numerous surveys were carried out at that time, starting with the search for ultraviolet excess galaxies by Markarian (1967) at Buyrakan while Zwicky (1971) was completing his first lists of blue and red "compact" galaxies. Since then other surveys have been carried out, either with different complementary techniques, or other much larger areas of the sky. A series of follow up studies involving spectroscopic and morphological material were pioneered by Petrosian, Sahakian and Khachikian (1978), showing the increasing importance of multiple nuclei in galaxies that undergo large episodes of star formation. Other studies by Huchra and Sargent (1973), the armenian astronomers (see Khachikian, 1978 for a review) and many others, were decisive to identify the main properties of new type of galaxies. The markland was made in the 70's with the seminal paper of Searle and Sargent (1972) recognizing the importance of blue compact *dwarf* galaxies as a new class of objects from their spectroscopical study of IZw18 and IIZw40. They were also named "extragalactic HII regions" and sometimes "HII galaxies" as their properties are almost undistinguishable spectroscopically from those of giant HII regions. Their properties make them suitable for studies abundances of their ISM abundances, star formation, galaxy formation and evolution and cosmology. I will review the most recent developments along these topics after a short summary of the main observational properties of blue compact dwarfs.

2. *Main general observational properties*. These galaxies have bluer colors ($U$-$B$=–0.6; $B$-$V$=0.0 to 0.3 on average) than ordinary irregular galaxies and their surface brightness is much higher. Their absolute blue magnitude, dominated by their stellar contribution, ranges from -17 down to -13. Spectroscopically they exhibit a high excitation spectrum with the forbidden line 5006Å to $H_\beta$ ratio ≥5. Such colors and ionization of the gas is due to OB stars complexes indicating a burst of star formation. A straightforward analysis of the ionized gaz spectrum leads to underabundances with respect to solar values. On the other hand their neutral gas contents is relativily high, amounting a few $10^7$ solar masses on average, or 0.3 to 0.5 times the luminous mass (on the other hand there are strong indications that the dynamical mass is much larger, in this case the HI mass would only represent around 0.1 of the total). All these properties show that these galaxies are the most chemicallyy unevolved galactic systems known, which undergo a strong burst of massive star formtaion. Their metal distribution peaks at 1/10th the solar value while the most deficient galaxy is IZw18 at about $Z_\odot/40$. Their present-day star formation rates range from 0.1 to 1 $M_\odot$/yr, involving thousands of massive stars. These figures indicate that such a rate, compared with the available HI reservoir would not be sustained over more than $10^8$ years. These galaxies hence, are potentially interesting for theories of star formation and galaxy formation. Some of them may be forming stars today although many of these dwarfs are obviously older systems that have undergone one or several bursts in the past. The study of their underlying older population using the HST may reveal time sequence among bursts (Hunter et al. 1995, but see Smecke-Hanes et al., 1994 and Tosi, 1993 who have performed similar study on spheroidal and nearby

dwarf irregular galaxies using modest-sized ground-based telescopes) and possibly an evolutionary sequence among diffrent type of dwarfs.

3. *Abundances*. Abundances most currently measured in blue compact galaxies are obtained from emission line studies of the nebular gas. In the optical, data have been extensively gathered for O, N, S, Ne, He and Ar while more recently Fe has been discussed from more accurate measurements (Thuan et al., 1995). With the launch of the HST other key elements such as C and Si have been measured. Until now, the ISM is found to be metal deficient with no exception. Four points are worth to outline:

1) recent studies from Thuan et al. (1995) of a set of 14 BCDGs selected from the First (FBS) and Second (SBS) Byurakan Surveys re-enforces previous claims that at low metallicity N is essentially primary. It remains surprising that the dispersion of the N/O ratio is found to be so small considering the weakness of the N lines at low metallicity and the fact that most of the N is in $N^+$ form forcing to adopt large correction factors for unseen stages. This study also shows that BCDGs show similar O/Fe overabundance with respect to the sun (around 0.34 in the log) as galactic halo by a Population III stars.
2) Dwarf emission-line galaxies are useful objects for studying the primordial helium abundance Yp, as it was pointed out by Searle and Sargent (1972) who found that IZw18 and IIZw40 were metal poor but have roughly solar helium, consistent with a primordial origin. For a long time a gap has been present in between IZw18 and most galaxies with metallicities peaking at around 1/5 to 1/10th. Objects from the Second Byurakan Survey now fill in this gap. One of the problems associated with the Yp derivation is the need to extrapolate the $(Y, Z)$ relationship to the zero intercept. Detailed reviews of the potential problems related with this derivation are discussed in Olive (1995) and Kunth (1995) for both statistical and observatioanl uncertainties.
3) On the other hand, the lack of known dwarf galaxies with abundances much smaller than in IZw18 is a long lasting puzzle. This led Kunth and Sargent (1986) to postulate that most metal poor galaxies such as IZw18 could be primordial objects in which the observed HII regions were too much self-polluted with supernovae ejectae ($\alpha$-elements) to exhibit their true abundance. They predicted that their neutral gas should be pristine. The Kunth et al. (1994)' HST-GHRS estimation of O/H in the cold HI of IZw18 indicates 1/1000 of the solar value in agreement with the self-pollution hypothesis. However their derivation suffers from large uncertainties (Pettini and Lipman, 1995) hence awaiting for confirmation.
4) The Hubble space telescope offers the possibility to observe a series of collisionally-

excited inter-combination transitions in the 1600-2000Å range. In particular it offers the possibility to derive C and Si abundances. The way C and O evolve with time is constraining for chemical evolution models since C is ejected with some delay with respect to the O elements. Garnett et al. (1994)' results appear to indicate that C, O,.Ne and S are mostly manufactured in massive stars rather than in intermediate mass stars. Si/O is found constant, very close to values in the solar vicinity. All pointing to the fact that Si is little depleted onto dust grains in giant HII regions.

4. *Star-formation studies.* Processes of massive star formation have been studied from the UV to the optical and the near IR. The concensus clearly states that star formation in Irrs and BCDGs processes in a discontinuous manner. Most synthetic stellar evolutionary studies hardly distinguish between a continuous burst lasting over less or equal to about $10^7$ years or an instantaneous burst in which all the stars are formed at once and evolve over time scales of few $10^6$ years. This distinction between both scenari appear less semantic that it looks *a priori* and is dicussed at large in Mas-Hesse and Kunth (1996). Their study also finds no evidence for large variations in the IMF (very close to Salpeter's value or slightly flatter), and no obvious trend with metallicity.

The importance of WR stars in HII galaxies has been considered many times (Vacca and Conti, 1992) and it can be seen that they are certainly one of the best

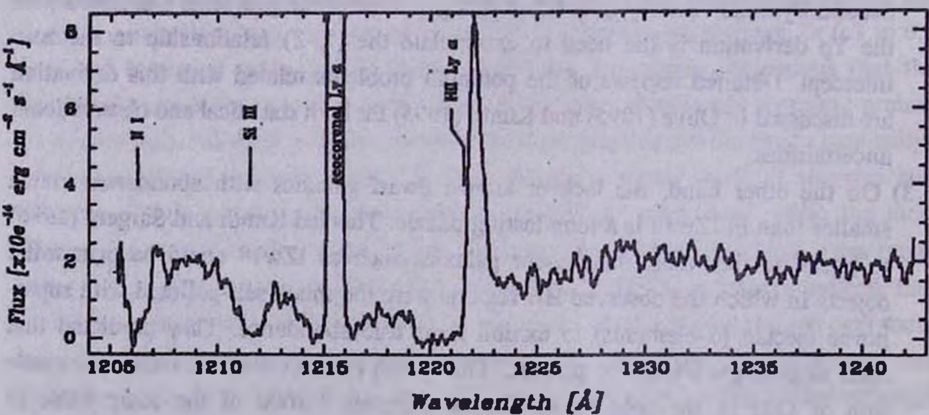


Fig. 1. Lyman α spectral region with the identification of some lines. The mark at 1221.6Å indicates the position of the Lyman α emission line according to the redshift derived from the optical emission lines. Note the asymmetry of the profile and the deep Lyman α absorption blueshifted with respect to the emission line.

constraining indicators for the nature of the star-formation machanism in BCDGs (Cervino and Mas-Hesse, 1994) in the sense that only instantaneous bursts can lead to large numbers of WR stars at a given time in HII galaxy as currently observed.

The impact of a starburst onto the interstellar medium has received observational new supports recently. It becomes clear that massive stars input large amounts of energy from supernovae and stellar winds (WRs). HST spectra of the BCDG Haro2 (Fig. 1) provide evidence for a gas outflow from the galaxy (more precisely the massive stellar cluster) at mean velocity of 200 km $s^{-1}$ (Lequeux et al. 1995). This is the probable detection of a *galactic wind* since it is very likely that the material will leave the galaxy. The mass of this shell is estimated to be of the order of $10^7$ solar masses hence the kinetic energy of such a shell expanding at 200 km $s^{-1}$ is $4 \cdot 10^{54}$ ergs comparable to that of the super-bubble discovered by Kamphuis et al. (1991) in M is $2.5 \cdot 10^{53}$ ergs, and the total energy of the expanding gas around the galaxy NGC 6946 is about $10^{55}$ ergs (Kamphuis & Sancisi 1993). The present kinetic energy of the Haro2 bubble is equivalent to the total energy of several thousand supernovae: this is a major phenomenon. Mas-Hesse & Kunth (1996) estimate a rate of supernova explosions of 1 per century in the HII region, producing a few $10^{54}$ ergs of total energy in say 1 million years. Other cases of outflows from blue compact galaxies have recently been presented. Papaderos et al. (1994) report X-ray emission in VIIZw403 as a result of a hot gas outflow from the core of this galaxy. Marlowe et al. (1995) bring convincing evidence for large scale expansion of the ionized interstellar media of dwarf galaxies.

If such ejected material can leave a galaxy, a likely possibility, this will strongly influence its chemical evolution. Metal-enriched galactic winds have been introduced (Marconi et al. 1994) to explain the chemical discontinuity observed between the HI and HII phases of IZw18 discussed above. Roy and Kunth (1995) pointed out that the mixing of elements in low-mass galaxies might be poorly efficient. Indeed stimulated star formation is much less effective than in large spirals, and the most powerful mixing mechanisms are absent; the escape of newly enriched material due to galactic winds powered by the starburst events, the lack of large-scale stirring, and the long dormant phase between successive star forming episodes make possible the survival of large abundance discontinuities. In order to reproduce the observed O/H value of the cold gas in IZw18 a chemical evolution model was presented by Kunth et al. (1995) showing that this galaxy must have experienced in the past one or at most two major events of star formation separated by a temporal gap of at least 1Gyr. However it is a curious observational fact that the N/O ratio in this galaxy is nearly solar making difficult to envisage a very short age for the ongoing burst if N were to be manufactured by the same star-formation episode than the O elements. Hence the N abundance argues in favor of a differential wind scenario *together* with primary production of N in massive stars. In such a picture type II SNe elements, such as oxygen, can be lost while elements such as N and He remain bound to the stellar region. Moreover regardless the exact adopted scheme (one or several burst/s) the production of stellar helium remains negligible. This reenforces the importance of extreme metal-poor galaxies for the primordial helium determination.

5. *What triggers star formation?* Starbursts and in particular BCDGs open the question of the origin for bursts. External events such as merging (IIZw40 is such a typical case), interacting systems (IIZw70-71 is a pair in which IIZw70 is undergoing a strong burst) can induce such large scale phenomenon. Cloud-cloud collisions is another appealling scenario. Constraints are given by the lack of pure HI clouds that sit in the sky with no optical counterpart. It is also possible to assume that after long time scales spontaneous star formation takes place followed by SN induced stochastic star formation. Recent developments along these ideas can be found in Vacca (1994, UV imaging), Taylor, Brinks and Skillman (1993a, b HI counterparts of HII galaxies) and Telles and Terlevich (1995, environments of HII galaxies). Some tantalizing questions are however pending:

i) why some extreme gas-rich galaxies spend long time (over $10^9$ years) in quiescent phase although their N(HI) exceeds $10^{20}$ atom $cm^{-2}$?
ii) what are the progenitors of BCDGs?
iii) what are the post-phases?

In a review paper entitled "The Dwarf Galaxy Star-Formation Crisis", Skillman and Bender (1995) review the ideas concerning the process of gas removal from dwarf galaxies at the onset of massive star formation, hence their relationship with formation and evolution of dwarfs. They suggest that neither the stripping scenario by which, in clusters one removes gas from dIs to make dEs, nor the one that pictures the evolution as a result of gas outflow by energetic events associated with star formation (SN and stellar winds) are globally satisfactory. Instead they argue for a more unified scheme making both type of dwarfs originate from a common ancestor that would have evolved via different star formation history.

6. *Cosmology.* The last topic i'll like to mention is cosmology. Here again, dwarfs are palying quite a role. One still imagine that they are the first entity to appear in the early Universe and that larger structures subsequently turn on from merging of these building blocks. Dekel and Silk (1986) suggested that cold dark matter cosmology with biasing would identify the formation of dwarf (all types) with density fluctuations of lower initial amplitudes than normal E and S galaxies. This scenario is no

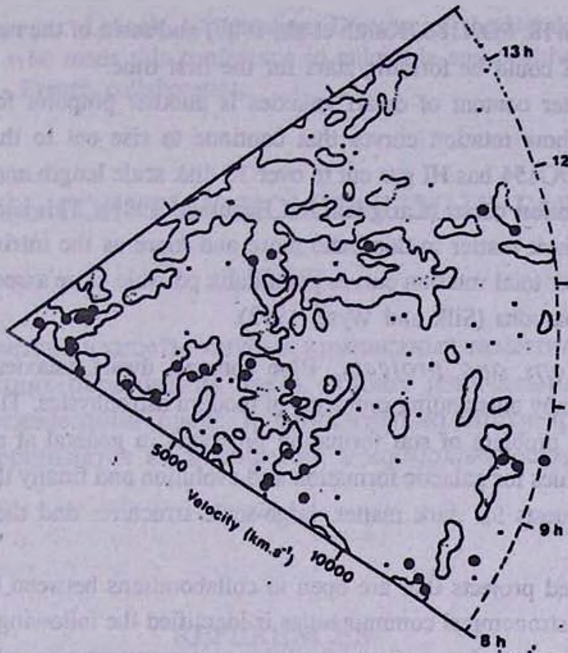


**Fig. 2. Cone diagram from Comte et al. 1994, showing a portion of the Center for Astrophysics "slices" of the northern sky. It shows that the observed distribution of the Kiso Ultraviolet Galaxies (black dots) coincides with that of the areas populated by the CfA galaxies (Light shade).**

longer valid partly because contrary to expectations it has been shown that dwarfs and emission-line galaxies are not found preferentially in the voids (Iovino et al., 1988; Salzer et al., 1988, 1989 a, b; Thuan, 1988; Comte et al., 1994, see Fig. 2).

Dwarfs may be parent populations of E and S galaxies. HST images do not provide complete answer to this problem and will possibly never do since imaging capability of the HST for the primordial galaxies search is limited by the image scale of the instrument. Further quasar absorption lines of the Lyman α forest may settle whether dwarfs are responsible for most of the observed lines. In this case the Lyman α lines would indicate that gas-rich dwarfs were more numerous in the past and have evolved in some ways. Finally the question remains to know whether some initial fluctuations still condense at present and form galaxies for the first time. Among BCDGs form a morphologically diverse sample (Loose and Thuan, 1985; Kunth et al., 1988), with some extreme examples being very compact with sizes typically below 1 kpc in diameter. No obvious triggering mechanism such as galaxy-galaxy interaction is visible.

Objects such as IZw18, POX186 (Kunth et al., 1988) and some of the new BCDGs that pertain to the SBS could be forming stars for the first time.

The dark matter content of dwarf galaxies is another pinpoint for cosmologist. Gas-rich dwarfs show rotation curves that continue to rise out to the most remote observed point. DDO154 has HI gas out to over 15 disk scale length and shows a clear turnover in its rotation curve (Carignan and Beaulieu, 1989). This seems to confirm the tendancy for dark matter to dominate more and more as the intrinsic luminosity decreases. Moreover total rotation curves point out a possible close association between dark matter and baryons (Silk and Wyse, 1993).

7. *Conclusions and projects.* Blue compact dwarf galaxies are obviously ideal targets for many outstanding problems of modern astrophysics. Their study sheds some light on the problem of star formation processes in general at any scale. They provide possible clues for galactic formation and evolution and finally they are relevant to cosmological quests for dark matter, large-scale structures and the first epoch of gaalxy formation.

Among selected projects that are open to collaborations between both the Armenian and French astronomical communauties is identified the following (that are hopefully not exhaustive since international facilities give many ways to submit interesting proposals as well):

i) deep surveys: the SBS and follow up spectroscopy and imaging will allow to increase the small known sample of potentially "young galaxies". Such a program permits to constrain the luminosity function of BCDGs at the very low-luminosity end. It will give further constraints on galaxy clustering.

ii) IR imaging: IR imaging will provide interesting clues on the presence of older population that underline the actual ionizing blue clusters. This can be achieved with modern large 2D IR receivers. IR spectroscopy will also be at reach for studying merging systems and the physics of the gas in dusty regions.

iii) The use of the HST gives the unique possibility to study the Lyman $\alpha$ emission that escaped from the HII regions in starburst galaxies, offering the opportunity to probe the HI gas and study C and Si abundances.

iv) Potentially spectro-imaging studies using multi-pupil spectrograph, long slit or multi-slit spectra will allow to understand the interplay between dust, ionized gaz and the properties of the star clusters (WR stars, O stars etc...).

v) the advent of large millimeter receivers (IRAM, ESO-SIST) leaves optimistic possibility in the future to reach enough sensitivity so as to be able to probe molecular gas in such metal-poor galaxies.

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## ВАЖНОСТЬ ГОЛУБЫХ КОМПАКТНЫХ ГАЛАКТИК

Д.КУНТ

Рассматривается важность голубых компактных галактик в современных исследованиях образования звезд, обилия изначальных и тяжелых элементов в межзвездной среде и относительно эпохи формирования галактик, подчеркивается их отношение к космологическим исследованиям.

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