ACTIVITY IN BLUE COMPACT GALAXIES

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ABSTRACT . This paper is aimed at providing a review of recent observational facts regarding blue compact galaxies. Tightening together flux measurements from the UV to the radio range now allow us to draw a somewhat improved, more self-consistent picture of these objects. Many questions are still open however, about their nature and evolution.

1. INTRODUCTION

Over the past three decades a wealth of extremely blue extragalactic objects have been discovered as several deep surveys became available. These socalled UVexcess galaxies were searched for in two ways essentially :
(i) examination of Schmidt plates obtained through different color filters, e.g. the objects to be found in Haro's list (Haro, 1956) and in Zwicky's catalogue (Zwicky, 1971) or the recent Kiso Observatory lists yielding some 3000 UVexcess galaxies within 1625 square degrees, up to m_p = 18 (Takase and Miyauchi-Isobe, 1986), (ii) objective prism works, e.g. the Byurakan observatory surveys (Markarian et al, 1979), the Tololo Curtis Schmidt (Smith, 1975), the University of Michigan (MacAlpine and Williams, 1981 and references therein) and the Cambridge UK Schmidt (McMahon et al, 1987) ones.

Resulting from a rapid increase in the number of UVexcess galaxies, a lot of specific studies regarding these objects are now in progress. A few warnings should be given however. First, each of these surveys is subject to definite bias which vary from one survey to the next and the compiled list of all UVexcess galaxies is far from representing a sample with statistical meaning. Second, the UVexcess light thus detected (around λ = 3500 Å) can either be produced by hot stars, or be of a nonstellar origin such as the thermal emission from an accretion disc or a nonthermal source of radiation. Third, these blue compact objects may be genuine isolated systems or part of larger galaxies. The overall sample is then extremely heterogeneous. Obviously, the primary searching procedure must be followed by detailed investigations like spectrophoto-

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metry and deep CCD images, in order to classify and better understand the nature of the so-called UVexcess objects.

What kind of astrophysical objects do we have identified up to now in this sample ? Essentially two classes can be defined : (i) *active galactic nuclei* which are distinguished by their point-like nonstellar radiation source are extensively discussed in previous contributions throughout this book and, (ii) *starburst galaxies* which are characterized by an intense star-forming activity.

Dealing with the second class only, the starburst may occur in various places within a galaxy. This leads to different structures and hence the following sub-classes :

- spiral galaxies having an intense disc starburst (e.g. Rosa,1980)
- galaxies showing starbursts in the vicinity of their nucleus otherwise normal (e.g. Sersic and Pastoriza, 1967 ; Alloin and Kunth, 1979 ; Weedman, 1983 ; Balzano, 1983)
- large, irregular galaxies with clumps of star formation (Huchra, 1977; Gallagher and Hunter, 1984) ; they are sometimes part of an interacting system as illustrated by the example of Mk 297 (Alloin and Duflot, 1979; Taniguchi and Tamura, 1986 ; Burenkov, 1986)
- small, isolated, irregular galaxies in which intensive star formation occurs through the entire galaxy body ; these object are the ones we are presently concerned with and from now on we shall focus on their properties. They are found in the literature, under various names : "isolated super associations" (Ambartsumian, 1966), "blue compact galaxies" (Zwicky, 1966), "isolated extragalactic HII regions" (Searle and Sargent, 1972) or "HII galaxies" (Campbell et al, 1986). We shall use the second terminology, abbreviated as BCG, and retain the definition given by McCall et al (1985) : "dwarf irregular galaxies whose optical presence is exemplified by an active region of star formation".

2. GENERAL PROPERTIES OF BLUE COMPACT GALAXIES

In which way do BCGs differ from classical irregular galaxies ? They show bluer colors than an average irregular, a higher surface brightness, and quite a large fraction of their mass is in the form of young stars as a result of gas rich content and on-going star formation at a large rate. For classification as a BCG, a galaxy must fulfill two conditions : it must have a compact structure and exhibit a high excitation spectrum with a typical line ratio value I([OIII]) / I(Hβ) > 5 (Fig.1). We recall that in classical disc HII regions, I([OIII]) / I(Hβ) is less than unity. Examples are IZw18, IIZw40, IZw36.... Since the pionneering work of Searle and Sargent (1972) this class of objects has been studied to some more extent (Alloin et al, 1978 ; Lequeux et al, 1979, 1981 ; French, 1980 ; Thuan, 1984 ; Kunth and Sargent, 1983 ; Viallefond and Lequeux, 1985 ; Sargent and Lo, 1986 ; Campbell et al, 1986 ; Pagel et al, 1986 ; Vigroux et al, 1986). Still many questions remain about their nature and evolution.

Most BCGs studied up to now, are dwarf systems having $-18 < M_B < -14$. There is a tendency to see tham as the dwarf end of a larger class of objects with M_B up to -23 (Hazard, 1986). Yet, no abundance determination is available for these non-dwarf systems while from that result it could

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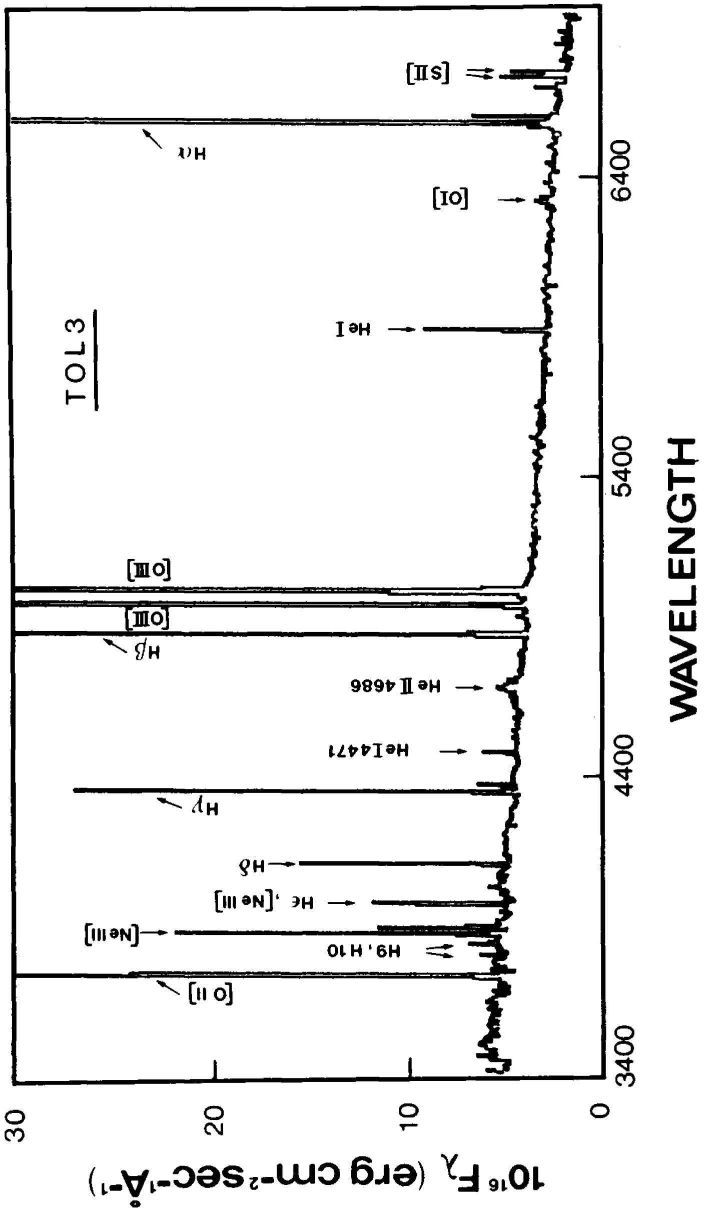

Figure 1 : The optical spectrum of Tol 3 (NGC 3125) corresponding to the brightest NW condensation (Kunth and Sargent, 1981). Courtoisy of D.Kunth and W.Sargent.

be decided upon, BCGs being characterized by lower than solar metal abundances. Parameter ranges for BCGs are given in Table 1 :

Table 1

M_B	-14 to -18 (up to -23 ?)
U-V	-0.4 to -0.8
B-V	0.4 to 0.0
HII region size	a few kpc (up to 10 kpc ?)
L(Hβ)	10^{38} to 10^{42} ergs s^{-1}
W(Hβ)	$\geqslant$ 50Å
O/H	1/2 to 1/40 the solar neighborhood value
Y	0.23 to 0.26
Z	0.0008 to 0.004
M_t	a few 10^9 $M_\odot$
M_{gas}	a few 10^8 $M_\odot$
Velocity dispersion	30 to 120 kms^{-1}
Environment	variable from one case to the other

As we already mentioned, BCGs are interpreted as gas-rich systems undergoing a very massive burst of star formation which dominates their light at nearly all wavelengths. Star formation rates from 0.1 to 1 $M_\odot$ yr $^{-1}$ are currently derived. The spectrum we observe in BCGs is essentially from the HII region generated around hot massive stars in the burst (from 10^4 to 10^7 O type stars, i.e., 10 to 10^4 times 30 Doradus). Neutral hydrogen is detected in BCGs in large quantities (M(HI) $\sim$ a few 10^8 $M_\odot$) and on a larger scale than the HII region itself (see for example IZw36, Viallefond and Lequeux, 1986). Hence it is generally assumed that the HII region is ionization bounded. Observed emission line ratios in the spectrum are consistent with ionization by hot stars. This allows a profitable analysis to be made, using current elaborate photoionisation models. From such studies, metal abundances have been found to be low in BCGs, down to $Z_\odot$ / 40 in the case of IZw18, and not larger than $Z_\odot$ /2.

Why should we study BCGs ? Being isolated dwarf galaxies, they appear as simple systems and we expect their evolution to be easier to understand. From the point of view of chemical evolution they are young systems and look therefore as *nearby examples* of galaxies in a phase of intensive gas-to-star transformation. BCGs then provide a unique opportunity for studying the initial mass function (IMF) under low metal content conditions and possibly in primordial gas clouds. Continuous star formation in BCGs is easily ruled out : it would have used up all the gas and produced too high a metal content. Given that star formation proceeds by bursts, it is necessary to find out the age and strength of the present burst as well as the frequency of such events in the lifetime of a BCG. The burst characteristics can be traced out through UV flux measurements, spectral line ratios and super-novae remnants altogether. Previous bursts have evolved and left behind an older stellar population which analysis would bring clues to the evolution of BCGs. This is however a difficult task to achieve because of the light-dominance from the present burst. More precise abundance determinations of He and heavy elements allow a better evolutionary scenario to be performed in BCGs.

Evolution of BCGs also depends on their dynamical properties and mass . It is then crucial to study as well their structure, their HI enveloppe and kinematics. Recent extension of the wavelength coverage, from X to radio, has allowed to study further the young and old stellar populations, the gas and dust content in BCGs. Only by tighting these results together can we get a self-consistent picture of what a BCG is and what its past evolution has been. We shall now review some recent progress in that matter.

3. RECENT DEVELOPMENTS ACHIEVED IN BCG STUDIES AND UNDERSTANDING

3.1 High energy flux,Xrays domain

BCGs have not yet been detected in this domain because of too low an Xray experiment sensitivity. I wish however to stress the fact that this is a promising way of tracing out SN remnants and binaries with compact massive companions to be found in intensive star formation regions. A good example of such an approach is the study of NGC 7714, the prototype of starburst nuclei, for which both Xray and radio flux measurements are consistent with the presence of about 10^4 SN remnants within a 300 pc radius region. (Weedman et al, 1981).

3.2 Ultraviolet observations of BCGs, the young stellar population

The International Ultraviolet Explorer , IUE, has been looking at about 20 BCGs, from 3000 Å down to 1250 Å. Data up to 1982 can be found in the Atlas of UV spectrograms (Rosa et al, 1984). The continuum in BCGs is generally found to rise to the UV more steeply than in other star forming regions. Apart from the case of IZw36, the UV spectrum is scarce in emission lines from the ionized gas contrarily to the visible one. The line most often detected, CIII] λ 1909, implies an effective temperature of the ionizing stars larger than 40 000°K (O5 main sequence stars). There is a tendency for CIII] to be more commonly observed in BCGs than in other starburst regions. This result suggests that the IMF gets enriched in massive hot stars when the metal content of the initial gas decreases. Again, Si IV λ1405 and CIV λ1550 PCygni profiles preferentially found in BCGs are the signature of massive O,B stars, early supergiants and Wolf-Rayet stars which are not detected in metal rich starburst nuclei for example. As a general figure, the total UV luminosity in BCGs requires 10^4 to 10^7 early massive stars ($M > 20 M_\odot$). A more detailed population synthesis for the starburst should make use of both the UV continuum and absorption lines equivalent widths, as well as other indicators derived from spectral line ratios.Main parameters featuring the observed UV emission are the *metallicity* (through blanketing effects), the *reddening* (which transfer UV energy into the IR domain), the *IMF* and the *star formation rate*.

Reddening problems are crucial in the UV and a major source of uncertainty in modeling starbursts. The dust content and subsequent

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reddening in BCGs has been approached through various ways. One can apply to the UV emission the reddening parameters derived for the nebular gas via a comparison of the theorical to the observed Balmer decrement value. Then, one must assume that both the light from the stars and from the gas are crossing the same amount of dust, a figure one cannot be absolutely confident about. A further uncertainty comes from the Balmer lines blend of nebular emission and stellar absorption. Using this method, Lequeux et al (1981) questionned whether the Galactic extinction law (Seaton, 1979) is still valid in the case of BCGs. They found rather that in a metal poor environment the far UV extinction curve rises at $\lambda < 1900$ Å. Else, one can derive the dust content using the strength of the 2200 Å dip and assuming the extinction law shape. Reddening in BCGs has been studied in that way by Gondhalekar (1986). Finally, population synthesis for the starburst can be run keeping the reddening value as a free parameter (e.g. Thuan, 1986) and again with the extinction law shape to be assumed. In this case, hypothesis about the IMF have to be made too. Particularly the effects of low metallicity on its high mass end are still disputed (Viallefond and Thuan, 1983). The general conclusion of these studies is that dust does not strongly affects the UV emission from low luminosity, metal-poor BCGs. However, a more precise outline of the starburst should be derived taking into account not only the outcoming UV emission but also re-radiated IR emission (60-100 μm) from dust heated by UV photons within the star-forming region (e.g.Weedman and Huenemoerder, 1985) .

Several attempts have been made recently to analyze quantitatily the young stellar component in BCGs (Benvenuti, 1983 ; Thuan, 1986 ; Gondhalekar, 1986). Both absorption lines and continuum points in the UV are used for this purpose. The main limitation in such works comes from the yet unclear dependence on the metallicity of the IMF and of the extinction law. Moreover, *age effects* have to be taken into account since both the duration and the starting time of each of the successive burst are important parameters in that matter. Young population analysis in BCGs are in continuing progress but still demand some careful attention.

3.3. Optical and UV spectral lines : abundance analysis

Much effort has been devoted to this topic in the past few years. The O, N, S, Ne and He abundances are derived from optical line analysis, while the C/O value has been deduced from UV faint lines, hence with less accuracy in three BCGs. Uncertainties essentially come from the complex geometry of the emissive regions, from the range in effective temperature for the ionizing stars, from the contamination by stellar absorption lines and last , from possible errors in the atomic parameters. (Pagel, 1986 ; Matteuci, 1986 and references therein). Some recent results are as follows : (i) the N/O abundance ratio in BCGs is uncorrelated with the oxygen abundance, consistent with most of N being of primary origin (Campbell et al, 1986). (ii) the effective temperature of the dominant ionizing stars increases with decreasing metal abundance in BCGs(Figs.2,3),a result which confirms the IMF dependence on metallicity (Campbell et al, 1986). (iii) the He abundance Y, by mass, seems to relate more closely to N/H than to O/H ($Z \propto O/H$) for a wide range of objects

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from BCGs to irregular galaxies. The Y, N/H and Y, O/H relationships provide a primordial Y_p value $Y_p = 0.237 \pm 0.005$, just consistent with current predictions based upon the standard Big-Bang model (Pagel et al, 1986).

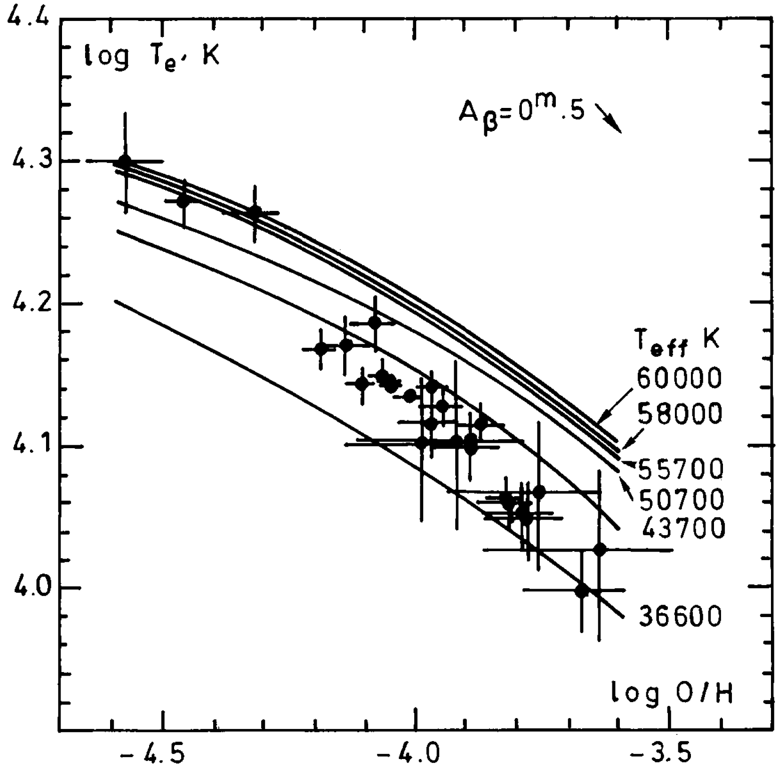

Figure 2 : The electron temperature ,T_e,plotted against the oxygen abundance.Curves of constant ionizing temperature are superimposed (Campbell et al, 1986).Courtoisy of R.Terlevich.

Regarding chemical evolution models, the validity of the instant recycling approximation has been questionned for BCGs (Matteuci and Chiosi, 1983 ; Kunth and Joubert, 1985). In the metal-poor objects IZw18 and IZw36, the total mass is found to be 5 to 10 times that of the HI gas ; still, no prominant old stellar population can be seen in these objects. Therefore, a bi-modal star formation process might be at work in BCGs. Chemical evolution in BCGs is found to be different from that in spirals, not only as a result of IMF variations but also possibly because of the influence of dynamics (Vigroux et al, 1986).

Recent studies of IZw18 (Davidson and Kinman, 1985 ; Kunth and Sargent, 1986) have re-open the questions of how fast are BCGs enriched in heavy elements from the massive stars they form, and what is the mixing length for newly formed heavy elements ? Indeed, O is released after 4 X 10^6 yrs while the production rate of the ionizing photons peaks before 10^6 yrs and is already down by the age of 4 X 10^6 yrs.Consequently, the O abundance we are measuring is from a previous, evolved starburst or the actual burst has been lasting for more than 10^7 yrs.

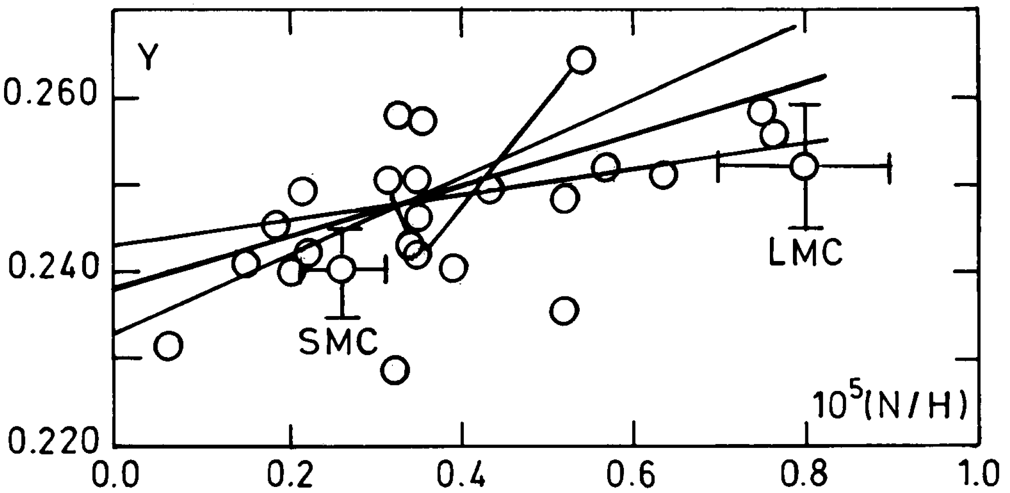

Figure 3 : Relationship between the Helium abundance Y,by mass, and N/H for BCGs and nearby irregular galaxies (Pagel et al, 1986).Courtoisy of B.Pagel.

3.4 Infrared colors : a probe for the old stellar population

Is the burst we actually see, the first one ? In the case of IZw18 and IIZw40, Searle and Sargent (1970) claimed that the mass trapped in old stars formed over the past 10^{10} yrs, is at most 40 times the mass involved in star formation during the past 10^7 yrs. Only a few of the BCGs seem to be without a possible older stellar component. However, it is difficult to sort out the number of past stellar generations. Metallicity in BSGs being still low, the level of star formation could not have been as vigourous in the past as it is now. To settle this question one can look at BCGs in near IR colors : an approach now widely used, thanks to CCDs. As an example, IZw18 is found to exhibit in the R filter a much more extended structure than that of the young star formation region as far known. Indeed many BCGs are now observed to have multiple star formation spots, i.e., belong to a larger system. Future studies of this type will probably modify our view about BCGs. One can use J, H, K flux measurements (1 → 3μm) to probe the old stellar component. However an ambiguity remains whether the near IR emission comes from old dwarf and giant stars, or from the young supergiant population associated with the starburst. A gravity discriminator like the IR CaII triplet (Jones et al, 1984) should be used to discriminate between the two possibilities. The IR continuum is low however, and absorption lines difficult to measure precisely.

3.5. The long wavelength range : HI and dust content, SN remnants

Recent observations of BCGs at the VLA (20 and 6cm) have shown the continuous radio emission to be consistent with the expected number of SN remnants in such objects (e.g. Brinks and Klein, 1986).

The HI gas structure observed in a few BCGs is clumpy and more extended than the optical, young stellar and red stellar populations, one. In that respect, BCGs show the disorganized, multiple gas cloud structure expected to characterize newly formed galaxies and for that reason are thought to be potential young galaxy candidates. They could however be old, that is formed at the same epoch than larger normal galaxies, but, due to their low mass, have needed more time to become virialized or simply organized and start producing stars on a large scale. In most BCGs the HI profile is gaussian, the signature of still disorganized motions. Hence, star formation could not proceed via density waves and has been probably rather stochastic.

Recent analysis of the IRAS flux measurements (Kunth and Sèvres, 1986 ; Dennefeld et al, 1986) show that about half of the BCGs are detected by IRAS (60, 100μm), and that the IR emission comes from HII regions, rather than giant molecular clouds.

4. CONCLUSION

The various terminologies used so far to name these objects demonstrate that they do not yet form a well-defined, homogeneous class. And this is not surprising since we have to deal with evolution too. What we know as their main common characteristics are : (i) their low metal abundance, (ii) their intensive star formation.

Their is no doubt that future studies will erase some of the many question marks we still have to use when discussing their nature or evolution.

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DISCUSSION

J. Melnick : I fully agree with you that BCGs are a very mixed class of objects which are very very difficult to quantify. However, if you restrict yourself to HII Galaxies (BCGs with giant HII region spectra), than you have a class which is very homogeneous and has the same properties as the giant HII regions I discussed. They satisfy the same correlations and can be very well modelled by single burst sysnthesis models.

A. Fairall : How can you be sure most of the mass is in young stars ? If this is so, it means the galaxy is only briefly visible when the starburst takes place. So there could be lots of invisible galaxies those still to have a starburst and those where the starburst is finished. Could you comment ?

D. Alloin : A fraction of the mass much larger than in conventional galaxies is in the form of young stars. However, both the mass trapped in old stars and the HI gas can be substantial contributors in these galaxies.

V. Komberg : What is the total spatial density of these objects ? Their luminosity function ?

D. Alloin : I think it is not yet possible to provide this information in a safe way !

N. Bochkarev : Do you know examples of enveloppe (ring -like) extragalactic HII regions or do they always show a concentration of gas to the center ?

D. Alloin : The structure of these objects is being studied with more care. Up to now, they have been selected on the basis of their compactness.

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