

BLUE COMPACT GALAXIES

In reference to the communication by Dr. Allan Sandage on the quasi-stellar galaxies (1965), attention should be called to the following pertinent facts.

A. THE NATURE OF THE QUASI-STELLAR GALAXIES

All of the five quasi-stellar galaxies described individually by Sandage (1965) evidently belong to the subclass of compact galaxies with pure emission spectra previously discovered and described by the present writer (Zwicky 1963).

For instance, the spectrum of Ton 256 as reported by Sandage (1965) is the same as that of the blue compact galaxy C_1 at¹ R.A. 11^h22^m7 , decl. $+54^\circ40'$, which was studied over two years ago (Zwicky 1963) and spectra of which were shown and reported at the International Astronomical Union (I.A.U.) Assembly at Hamburg, August 25–September 3, 1964, and at the Padua Symposium of the Giornate Galileiane (Zwicky 1964*a*, *b*) September 15–18, 1964.

For C_1 the line $H\gamma$ in emission has a width $\delta\lambda \cong 62 \text{ \AA}$, and the bright line $\lambda 3727.3$ [O II] has a width $\delta\lambda \cong 17 \text{ \AA}$, both broadened in equal relative proportions as the same lines in Ton 256. It should be noted that C_1 is identical with LB 2012 (Luyten 1958) and that it was originally mistaken for a star. The symbolic heliocentric velocity of recession of C_1 is $V_s = c \delta\lambda/\lambda = +6250 \text{ km/sec}$ (not corrected for galactic rotation).

The second object reported by Sandage, Ton 730, has a spectrum which is similar to that of the compact galaxy C_2 at R.A. 16^h22^m1 , decl. $+41^\circ12'$ (Zwicky 1965*a*, *b*), the symbolic heliocentric velocity of recession for which is $V_s = +10250 \text{ km/sec}$. Its indicative² absolute photographic magnitude is $M_p = -19.7$.

The third and fourth objects reported by Sandage (1965) without coordinates, namely, "Near 3C 194" and BSO 105 are described as having continuous spectra which extend far into the ultraviolet with no obvious emission or absorption features. In this they are similar to the spectra of compact galaxies like C_3 at R.A. 17^h27^m1 , decl. $+50^\circ15'$ (Zwicky 1964*b*, 1965*b*).

And finally, the fifth object reported by Sandage (1965) appears to have a spectrum, not definitely identified, which is similar to that of the compact galaxy C_4 , the description of which was reported on several occasions during the past two years (Zwicky 1963, 1964*a*).

Three lists containing about 600 compact galaxies have been prepared for distribution (Zwicky 1964*b*, 1965*a*). The first was distributed at the I.A.U. Assembly in Hamburg while the second and third lists were issued March 18 and May 1, 1965.

The objects C_1 , C_2 , C_3 , C_4 are radio-quiet to the level of 9 flux units $= 9 \text{ W m}^{-2} (\text{c/s})^{-1}$ at 178 Mc. Not over about 5 per cent of the compact galaxies reported in the above-mentioned three lists have radio emission above this flux level. The existence of a large class of radio-quiet stellar-like extragalactic objects with spectra similar to those of the quasi-stellar radio sources was thus established through the investigations of the compact galaxies (as reported at Hamburg).

Dr. H. C. Arp (1965) kindly informed me that he has recently also obtained spectra of some nearby ($V_s \sim +1000 \text{ km/sec}$) emission-line objects which belong to the subclass of blue compact galaxies. The indicative absolute photographic magnitudes of the blue compact galaxies so far investigated individually by the writer have been found to range from $M_p = -11.0$ to $M_p = -23.0$ (Zwicky 1966).

B. BLUE COMPACT GALAXIES AND THE SEARCHES FOR BLUE STARS IN HIGH LATITUDES

The first search in 1938–1940 for blue stars in an area of 400 square degrees near the north galactic pole by the writer (Humason and Zwicky 1947) with the 18-inch Schmidt

¹ All coordinates given in this Letter are for the epoch 1950.0.

² For the definition of indicative absolute parameters see Zwicky and Humason (1960).

telescope netted the thirty-three objects, HZ 16 to HZ 48, thought to be stars. The subsequent spectroscopic investigation by Humason revealed HZ 46 to be extragalactic. It is a blue compact galaxy with extensions, showing a continuous spectrum with the bright line $\lambda 3727.3$ [O II] shifted to the red by an amount which is equivalent to a symbolic heliocentric velocity of recession $V_s = +13418$ km/sec. This, with $m_p = 14.7$, makes the indicative absolute photographic magnitude of HZ 46 equal to $M_p = -20.9$, or, with a Lundmark-Hubble constant of 75 km/sec per million parsecs, as proposed by Sandage (1965), $M_p = -21.5$.

Similar misidentifications were initially made when searching for blue stars with the 48-inch Schmidt telescope. For instance, on a three-image plate, using the Haro-Luyten method, the object (Ambartsumian knot) at R.A. 11^h08^m5 , decl. $+28^\circ57'$ appears starlike, with an ultraviolet excess of about 1 mag., while the spectroscopic investigation with the 200-inch telescope revealed it to be an emission-line galaxy (Zwicky 1958), $V_s = +8900$ km/sec and indicative of absolute photographic magnitude $M_p = -15.9$. Two objects which are neighboring to the Ambartsumian knot and which cannot be distinguished from stars on direct photographs (Zwicky and Humason 1961) with the 200-inch telescope also revealed themselves as emission-line galaxies when studied with the prime-focus spectrograph of the 200-inch telescope (Zwicky 1958). These examples led me to the conclusion, stated in my final summary of the Strassburg Symposium on faint blue stars (Luyten and Zwicky 1965) that, among the objects found as a result of the surveys for blue stars by Haro and Luyten (1962), and Berger with the 48-inch Schmidt, as well as from my own surveys with the 200-inch telescope (Zwicky 1957), many would be found not to be stars but extragalactic objects of the subclass of the blue compact galaxies. Further confirmation of this conclusion was produced by my former collaborator on the blue star program, Dr. J. Berger. In comparing the lists of radio sources with the blue star catalogue of Luyten and Haro he found a number of positional coincidences which he communicated privately to colleagues working on the blue star program (Zwicky 1965c). Most strikingly, the quasi-stellar radio source 3C 9, for which Schmidt (1965) found the greatest redshift known so far, is identical with the "blue star" PHL 2871. As to the spectra of these galaxies it is of importance to note that they show permitted and forbidden emission lines of all the elements which contribute to the spectra of the quasi-stellar radio sources, notably H, He, C III, C IV, [O II], [O III], [Ne III], [Ne V]. In some objects all lines may be of the same relative width $\delta\lambda/\lambda$, while in others they may be roughly inversely proportional to the square root of the mass of the emitting atoms. On the average one compact galaxy per 5 square degrees and brighter than $m_p = 17.0$ is found which is identifiable with the 48-inch Schmidt. Twenty per cent of these are blue. Thus we have about one such blue compact galaxy, distinguishable from stars, per 25 square degrees.

Since the surveys for blue stars have been found to yield blue pygmies, white dwarfs, subdwarfs, horizontal-branch stars, blue giants, remnants of novae and of supernovae as well as compact blue galaxies and quasi-stellar radio sources, the problem is to determine observationally the relative frequency of occurrence of these objects.

C. STATISTICS OF BLUE STARLIKE OBJECTS

1. For the Humason-Zwicky stars HZ 16 to HZ 48, designating with $N(m_p)$ the total number of stars brighter than m_p and writing $\log N = a m + \text{const.}$, we find that a at the bright end, for $m_p = 10.5$, has the value 0.6 and that it then steadily decreases until $m_p = 15.5$.

2. Eight hundred blue stars found by Luyten and Miller (1956) with the Michigan Curtiss-Schmidt telescope in about 1100 square degrees of regions of low interstellar obscuration give a $\log N(m)$ -curve with an almost constant slope of $a \cong 0.6$ for the range $m_p = 13.0$ – 17.0 .

3. For 900 stars found on Tonantzintla plates (Luyten 1958) in 250 square degrees in Ursa Major, α , which is equal to about 0.6 at $m_p = 12.5$ declines steadily with m_p up to $m_p = 17.0$.

4. $\log N(m)$ for all of the 8746 Tonantzintla objects (Haro and Luyten 1962) is of the character shown in Figure 3 of the article by Sandage (1965). In the analysis of the integral number counts $N(m)$, carried out 2 years ago in detail by Mrs. J. Berger and F. Zwicky (Zwicky 1963; Luyten and Zwicky 1965) the integral count-curves were plotted separately for the three classes of stars $0 \geq U - V \geq -0.1$, $-0.1 > U - V \geq -0.3$, $-0.3 > U - V \geq -0.9$. These curves, although similar in character to the integral curve for all Tonantzintla stars, nevertheless have different slopes and curvatures and, most significantly, cross each other.

The analyses 1, 2, 3, and 4 indicate that no unambiguous conclusions as to the relative numbers of blue stars, nearby compact galaxies, and very distant blue galaxies can as yet be drawn from the study of the integral count-curves $\log N(m)$ based on available lists. In any event, even if we assume that the curve shown by Sandage (1965) in his Figure 3 accurately represents the distribution of the blue stellar objects in depth of space, the conclusion that the major fraction of the Tonantzintla objects are exceedingly distant galaxies appears doubtful. If this were really the case, the $\log N(m)$ -curve would first have to reach a slope of $\alpha = 0.6$ and then bend over to smaller slopes. This evidently is not the case. Mrs. J. Berger and Zwicky (Zwicky 1963; Luyten and Zwicky 1965) have also made an analysis of the areal (lateral) distribution of the Tonantzintla stellar objects, the results of which tend to confirm the conclusion that only a small fraction of these objects can be at indicative distances greater than 500×10^6 pc. Indeed, the study of the so-called dispersion subdivision curves (Zwicky 1957) shows that these curves for the Tonantzintla objects resemble those of the halo stars in general, as well as those of the nearby galaxies, while they differ radically from those derived for the distribution of galaxies on limiting plates of the 48-inch Schmidt telescope (Luyten and Zwicky 1965).

F. ZWICKY

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MOUNT WILSON AND PALOMAR OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON
CALIFORNIA INSTITUTE OF TECHNOLOGY

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