The Revised 3C Catalogue of Radio Sources

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Dr. Philippe Véron of the Paris Observatory is well known for his work on the optical identification of radio sources. He is presently spending a two-year period with the ESO Scientific Group in Geneva, together with his charming astronomer-wife, Dr. Mira Véron. In this article, Dr. Véron discusses the importance of optical observations of extragalactic radio sources for determining the type of universe we live in and summarizes the present status of the 3CR radio survey.

In 1935, extraterrestrial radio waves were discovered by Jansky. The first discrete radio source was discovered in 1946, in Cygnus, by Hey, Parsons and Philipps. A few more were discovered in the following years by Bolton and his co-workers who in 1949 were able to identify Virgo A and Centaurus A with two giant elliptical galaxies: NGC 4486 and NGC 5128. It became obvious that a systematic survey of the sky should be undertaken to study this new population of extragalactic radio sources.

After a preliminary survey, known as 1C, of about 50 discrete sources, a large interferometer was constructed in Cambridge, consisting of four parabolic cylinders. With this telescope, at $\lambda = 3.7$ m ($\nu = 81$ MHz), Ryle and his colleagues attempted in 1955 an extensive survey of radio sources, labelled 2C.

In Sydney, a survey using a different type of radio telescope, but at the same wavelength, was at this time conducted by Mills and his group. Part of the sky was surveyed both in England and in Australia. The two lists of sources were compared, and the disagreement was almost complete; hardly any of the individual sources corresponded. The reason for this disagreement was confusion which mainly affected the Cambridge survey. Confusion arises from the limited angular resolving power of radio telescopes; if the sky density of sources is large, the probability for two or more sources to appear in the same beam or field of view of the telescope will also be large, producing a number of spurious sources having an apparent flux density larger than the limit of the survey.

It was eventually realized that confusion is a serious problem if the number of sources listed exceeds about one source per 25 primary beam areas. With the same interferometer adapted to a shorter wavelength, $\lambda = 1.9$ m ($\nu = 159$ MHz), in order to reduce the beam area, a new and more reliable Cambridge list of 471 sources, the 3C Catalogue, was published in 1959.

New observations at $\lambda = 1.7$ m ($\nu = 178$ MHz) led in 1962 to the publication of the "revised 3C Catalogue of radio sources" (3CR). It is a survey of the sky north of declination $\delta = -5°$, including all point sources with a flux density greater than 9.0 Jy (1 Jy $= 10^{-26}$ w m^{-2} Hz^{-1}; Jy = Jansky).

The 3CR catalogue was the first reliable list of extragalactic sources to have been published. Among the 328 sources contained in this list, 29 are galactic: HII regions or supernova remnants.

In 1951, Smith's very accurate radio position for Cygnus A enabled Baade and Minkowski to identify this source with a faint galaxy of great radial velocity ($V_r = 16{,}800$ km/sec, $z = 0.057$). The discovery of this object had a great importance because it revealed that a radio source similar to Cygnus A, but with a flux density of 9 Jy (the limit of the 3CR catalogue), would be at a very large distance ($z = 1.8$ if $q_0 = 1.0$, $z = 1.2$ if $q_0 = 0.0$); i.e. a deep radio survey would contain cosmological information.

If the number density of radio sources is uniform and the space-time geometry Euclidean, the number of sources N with power flux density greater than S should be inversely proportional to $S^{1.5}$; i.e. a logarithmic graph of N against S would have a slope of -1.5. In an expanding universe, the slope can only be larger than this value. Scott and Ryle in 1961 showed that the logN/logS curve for the 3CR sources has a slope of $-1.80 \pm .12$, indicating an excess of faint sources which may be most easily explained by assuming an evolution with time of the radio sources; the density of the strongest of them decreasing as time increases.

A large number of deeper surveys, covering a large range of wavelengths, have been published since 1962; but the 3CR contains the strongest sources which are the easiest to observe, and it is the oldest, so after 15 years it is by far the best known sample of radio sources.

Most of the 3CR sources have been mapped with a very high resolution, and their radio spectra are accurately known over a large interval of frequencies. For the 255 sources outside the galactic plane, the identifications with optical objects, quasars or galaxies, most of them giant ellipticals, are complete to the limit of the Palomar Sky Survey (about 20 mag), following the initial pioneering work of Véron and Wyndham.

Moreover, many of the fields which are still empty on the Sky Survey have been photographed with large telescopes by Gunn, Kristian, Longair, Sandage, Spinrad, Wlérick and others, allowing identifications to be made with objects as faint as the 23rd magnitude. Recently, Longair und Gunn have shown that at the limit of ~23.5 mag, only 5 per cent of the sources in a large region of the sky were still unidentified. This fraction will obviously be larger in a deeper radio survey.

A large number of redshifts (163) have been measured for these identifications. In 1960, Minkowski measured the redshift of 3C 295.0, a very faint elliptical galaxy with $V = 20.1$ with the Palomar 5 m telescope. From two spectrograms of the galaxy, totalling 13.5 hours of exposure time, he found $z = 0.46$. He would not have been successful if the galaxy had not had a very bright [OII] λ 3727 emission line.

This was for many years the record redshift for a galaxy, but now thanks to the effort of Kristian, Sandage, Westphal, Spinrad and Smith, using new linear detectors, eight additional redshifts have been measured larger than this value, reaching $z = .81$ for 3C 265.0, for galaxies as faint as $V = 21.0$. All these galaxies have emission lines in their spectra.

We may hope that in the near future the redshifts will have been measured for all 3CR galaxies brighter than $V = 20.5$ (about 20 remaining). About 70 sources would then be left unidentified, or identified with galaxies fainter than $V = 20.5$. The Space Telescope may enable us to identify and measure all of these objects. Then, for the first time, we will have a complete sample of radio sources, completely identified. This is extremely important as it will then be possible to measure directly the time evolution of the luminosity function of radio galaxies, and perhaps to put an upper limit to the value of the acceleration parameter q_0, as we expect a larger number of large redshifts for $q_0 = 1.0$ for instance, than for $q_0 = 0$.

But before reaching any conclusion from the analysis of the 3CR Catalogue, we have to ask ourselves the following question: is this sample really complete and unbiased? A recent study has shown that this is not the case. The antenna beam width of the Cambridge radio telescope used for preparing this survey was 13ʹ.6 EW and 4°.6 NS. This beam width is so wide that some 3CR sources may still be affected by confusion of nearby sources. This could fortuitously raise the combined flux of the 3CR source and the confusing source above the catalogue limit of 9.0 Jy.

The more recent 4C catalogue is complete to 2.0 Jy (at the same frequency of 178 MHz). A search for all 4C sources in the neighbourhood of each 3CR source and a careful study of their radio spectrum (higher frequency measurements are usually not affected by confusion) have led to the rejection of 59 sources, whose flux density is lower than 9.0 Jy. In addition, 9 new sources were added which do not appear in the original 3CR because of resolution effects. Their angular size is so large that their peak flux density measured with the 3CR instrument was below the limit of 9 Jy. The corrected 3CR sample then contains only 205 sources outside the galactic plane. The slope of the logN/logS curve for the original 3CR is −1.80; for the new sample it is only −1.70, which makes the necessary time evolution somewhat less strong than anticipated, the excess of faint sources being smaller.

In conclusion, we may say that because of the tremendous amount of data accumulated in fifteen years on the 3CR sources, and although a large amount of effort and telescope time is still needed before the distance of all sources in the corrected 3CR sample is known, this is certainly a worth-while project as it will give us a better knowledge of the evolution of radio sources and perhaps some limitation on the possible value of the acceleration parameter q_0.

We must add that some more radio data are needed because for a few sources (like 3C 105.0, 3C 300.1, 3C 306.1, 4C −01.04, 4C 73.08, the last two not appearing in the original 3CR) the radio structure and position are not known well enough to make an unambiguous identification.

As an example, let us take the case of 3C 321.0. For many years, it was believed to be a single source in an empty field, but in 1974, Högbom and Carlsson showed with the Westerbork radio telescope that in fact it is an asymmetrical triple, the central component coinciding with a 16th-mag galaxy at z = 0.1.

Obviously, the study of deeper or higher frequency surveys should not be neglected as they will bring complementary and very useful information; but still a study, as complete as possible, of this limited sample of 205 extragalactic sources should have a high priority.

STATE OF IDENTIFICATIONS IN THE ORIGINAL AND IN THE CORRECTED 3CR SAMPLE

Total number of sources 161 ≥ 10°	Original 3CR		Corrected sample	
	255	%	205	%
QSS (no z)	55 (7)	21	45 (4)	22
Galaxies with z <.200 (no z)	77 (2)	30	70 (3)	35
Galaxies with measured z >.200	40	16	29	14
Galaxies without z, m_{pg} <21.0	19	8	14	7
Galaxies without z, m_{pg} ≥21.0	20	7	16	7
Empty fields	40	16	27	13
Absorbed fields	4	1.5	4	2

Two New Stellar Systems Detected on ESO Schmidt Plates

Last year, two new irregular dwarf galaxies were discovered on ESO Schmidt plates in the constellations Phoenix and Sculptor (*Messenger* No. 7, December 1976). Now, continued inspection of plates taken for the ESO (B) Survey has revealed another two, hitherto unknown stellar systems in Eridanus (River Eridanus) and in Sagittarius. Both objects have been photographed with the ESO 3.6 m telescope, and some preliminary conclusions may be drawn about their nature although further observations are clearly needed for confirmation.

The *Eridanus* object (Fig. 1) lies at position R.A. = $04^h\ 22^m.6$; Decl. = −21° 18ʹ (1950), only 3.5 arcminutes northwest of the 8th-magnitude star SAO 169422. There are reasons to believe that it is an intergalactic globular cluster. Assuming that the brighter, central stars, which are relatively red, are typical globular-cluster red giants of population II, ESO astronomers H.-E. Schuster and R. M. West

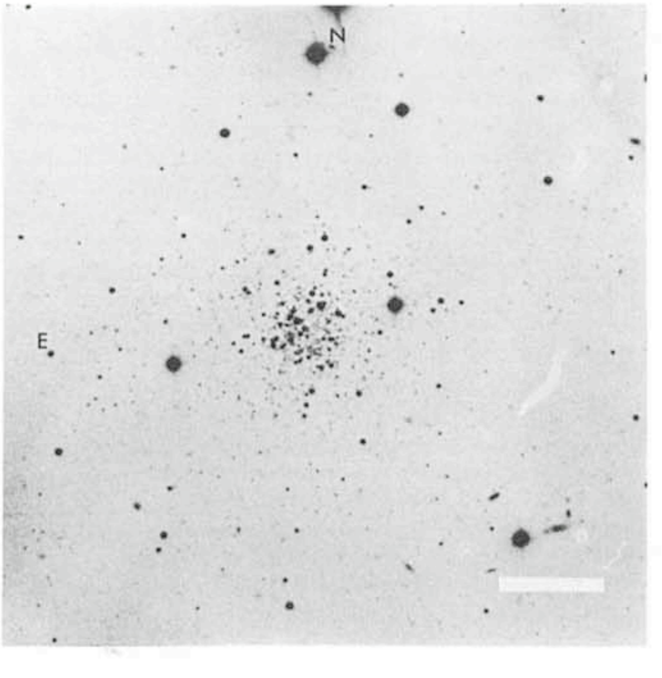

Fig. 1. — *Photo of stellar system in Eridanus obtained with the ESO 3.6 metre telescope in prime focus. Exposure time 90 min on IIIa-J + GG 385. Observer: H.-E. Schuster. The scale is indicated by the 1-arcminute bar.* ▶