PAPER 97

CONCLUDING LECTURE *by*

R. MINKOWSKI

Mount Wilson and Palomar Observatories, Pasadena, California, U.S.A.

The lively and extended discussions in this session have given to some extent an unduly pessimistic picture of the present state of the investigation of faint radio sources. It seems necessary to emphasize the fact that progress has been made, even if relatively few results are definitive and few problems have been solved.

The new observations of normal bright galaxies, reported by R. Hanbury Brown (paper 85), seem to establish the fact that many bright galaxies are sources with an intensity closely correlated with the optical brightness. For the galaxies that were observed as sources, $m_r - m_p$ has a mean value of about 0.8 magnitudes with a dispersion of only a few tenths of a magnitude. Such a result justifies the concept of "normal" galaxies. But the result has a very puzzling aspect. The photographic magnitude is not a measure of any quantity directly connected with radio emission. It contains contributions of both Population I and II stars whose relative importance differs for the various types of galaxies. Since elliptical galaxies, which contain only Population II, have not been observed as radio emitters, it would seem reasonable to expect a large value of $m_r - m_p$ for galaxies in which the content of Population II contributes much to the photographic brightness. In line with this expectation NGC 4594, the Sb-type galaxy with the extreme content of Population II in its bright spheroidal mass, has not been observed as a radio source. It is astonishing that, with the exception of NGC 4594, all Sb and Sc galaxies and even the irregular galaxies dominated by Population I seem to have the same value of $m_r - m_p$. A more careful determination of the integrated radio magnitudes and the use of more reliable photographic magnitudes are needed before this result can be considered as definitive.

The discussion of the relative merits of the pencil-beam instruments and the interferometers for surveys of radio sources has perhaps tended to obscure the merits of the interferometer, which under favorable circumstances can give us the most accurate positions in right ascension. Actually, as Ryle has emphasized (paper 86), there is no basic difference between pencil-beam and interferometer as regards the effects of confusion. The main difference between the Sydney and the Cambridge surveys is the fact that the Mills cross is sensitivity limited, while the Cambridge interferometer is confusion limited. The inability of the interferometer to record sources beyond a certain size is an inherent difference, however.

It is now generally recognized that the Cambridge survey at 81.5 Mc/s was very severely affected by confusion. The new survey at 159 Mc/s is obviously much improved, but it is not free of the effects of confusion. Also, sources larger than 5 minutes of arc are not recorded by the Cambridge interferometer. The Mills cross on the other hand is not affected by confusion and will record all sources regardless of size. Side-lobe effects, however, may produce spurious sources, which should be relatively more frequent among the fainter sources.

What one should expect if the results of the two surveys are compared is that at high flux densities not all sources recorded by the Mills cross should be observable with the Cambridge interferometer. But the positional agreement should be good for all sources recorded by both instruments. As one proceeds to fainter sources, the effects of confusion should increase. The interferometer should now begin to fail; some sources may no longer be recorded in the proper position and spurious ones may appear. There is no reason to believe that the Mills cross will show a very large fraction of spurious sources due to side-lobe effects, but a certain number undoubtedly will exist, increasing the discordance between the surveys. What happens is exactly what one should expect: almost every source that shows a record of good quality in the Cambridge survey agrees well with a source of the Sydney survey, but the very much poorer agreement for fainter sources renders an overall picture that is still quite unsatisfactory. As a sign of progress one may note that in the area common to the two surveys there are now 43 sources for which the agreement is good; this is not a negligible addition to the 38 well-determined sources in Pawsey's catalog of 1955.

It is quite obvious that only observations with several instruments of different types can give a completely reliable list of sources. The first results obtained with the great interferometer at Nançay that were reported by Boischot (paper 89) promise important contributions. But pencil-beam observations in the Northern Hemisphere are badly needed; the 250-foot radio telescope at Jodrell Bank may fill this need. In the Southern Hemisphere, observations with an interferometer could contribute much, particularly by giving higher positional accuracy in right ascension.

Attempts to identify radio sources have now been made by several investigators. All these attempts have led to the same result: not more than a small fraction of the sources can be identified with optical objects. The number of identified sources has been increased. It seems now that some multiple elliptical galaxies, e.g. NGC 6166, have to be added to the systems that show strong radio emission, but no explanation can be offered at this time about what distinguishes a small fraction of such objects from the great majority that do not seem to be strong emitters. One fact seems definite. If all sources at high galactic latitudes are extragalactic—an assumption that is not beyond doubt—those with $m_r - m_p > -7$ magnitudes should be galaxies brighter than 17th magnitude, easy to identify with the present positional accuracy. That only few sources can be identified, most of them with objects for which $m_r - m_p < -7$ magnitudes, indicates directly that there are relatively very few intrinsically faint extragalactic sources in the present lists.

Since information on the nature of the sources seems difficult to obtain from identifications, the application of radio methods gains increased importance. Measurements of the nebular red-shift for the 21 cm line obviously would be most desirable, but not many sources can be reached with present techniques. The measurements of angular sizes, which are now becoming available in increasing numbers, promise significant progress, apart from their value for identification. The most important fact shown by these measurements is the existence of smaller and thus presumably more distant sources than Cygnus A. Ryle's discussion of the nature of radio sources (paper 94) shows that even at the present stage, with small numbers of identifications and of known angular sizes, valuable information can be derived. The result that most sources now observed must be strong emitters, such as Hydra A or Cygnus A, fits well with the difficulty of finding identifications.

The fact that sources such as Cygnus A can be observed at distances beyond those reached by optical telescopes clearly suggests that observations of radio sources may provide new ways of attacking cosmological questions. The study of the number-intensity relation, which seemed one possible way, has not yet led to definitive observational results. Mills (paper 91) finds now from counts of 1002 sources a slope of -1.65 for the best fitting straight line in the plot of $\log n$ versus $\log S$. The deviation from the value -1.5 for a random distribution in a static Euclidean universe is not significant. Shakeshaft has reported a slope of -2.2 from counts of 85 sources between declinations $+37$ and $+52$ degrees and a slope of -2.7 for 162 sources between declinations -10 and $+10$ degrees. The number of sources in these counts is too small to attribute much weight to them. Scheuer has attempted to avoid the effects of confusion by investigating the statistics of the deflections recorded with the Cambridge interferometer. This seems to be a powerful method, but it does not remove the effects of the finite sizes of sources. The result of this attack on the problem is that the observed frequency distribution of small deflections is in agreement with a uniform distribution of sources, but that there is a deficiency of large deflections. No agreement has been reached on the question of whether this discordance can be understood as an effect of the finite sizes of sources. All results can be explained, as Shakeshaft has mentioned, by a deficit of intense sources. Whether this interpretation is correct can only be decided by deeper surveys that reach substantially larger numbers of sources. This is the only possible way to remove the influence of a deficiency of intense sources that, however unlikely, may exist as a statistical fluctuation in our neighborhood.

At this moment the available data are obviously not a sound basis for cosmological discussions. Hoyle's excellent concise report (paper 95) and McVittie's remarks (paper 96) show that even reliable counts of sources may not be adequate to select a unique cosmological model. The problem is indeed not basically different from that in optical astronomy, where counts of galaxies do not seem to provide a manageable way to attack the cosmological problem. The existence of a minimum apparent size in certain cosmological models puts additional emphasis on the importance of measurements of angular sizes. But it seems clear that considerable time will elapse before the study of radio sources has reached a stage in which the results may be used with confidence to attack cosmological problems.

https://doi.org/10.1017/S0074180900051433 Published online by Cambridge University Press