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Surveys of Structure in Strong Radio Sources (J.S. Ulvestad)

Introduction

In many ways, surveys are inherently boring. Naturally, surveys of surveys are even more boring. Therefore, rather than concentrating exclusively on a summary of the work that has been done, this lecture will take a more philosophical point of view. The emphasis will be on what can be learned and how we learn it. Only after the approach has been established will a few of the recent results be described.

Some of the questions which must be considered in any survey of radio structures are listed below:

1) What can we learn from studies of a large sample as opposed to detailed investigation of a single object?

2) How do our prejudices affect what we think we learn?

3) How important are selection effects?

4) What has been learned so far?

The talk is organized into four parts:

I. Philosophy
II. Source Selection
III. Goals
IV. Results

I. Philosophy

The approach to a survey of radio source structures is akin to surveys which are made in a wide variety of fields. Indeed, one can establish a general framework for a study without knowing much about radio astronomy or radio sources. The key is to establish what problems should be attacked and how the information bearing on those specific problems can best be obtained.

To prove that a general philosophy must underlay many different types of surveys, I will address a field totally removed from radio astronomy -- long-distance running. In particular, I will look at the ~ 10,000 runners who finish the New York Marathon and show that there are four different types of studies which can be made, each having its ~~own~~ advantages and disadvantages. One may study each of the four individuals/groups listed below:

Set A) Bill Rodgers, 4 time winner of the race
Set B) The top 100 finishers in 1980
Set C) Every 100 th finisher from 100-10,000
Set D) A set of 100 finishers in the middle of the pack, from 5000th to 5099th place.

Studying Set A will give information on a unique individual who may be a fluke. Although Bill Rodgers cannot be considered a representative runner, the advantage is the availability of a great deal of information.

Set B contains a large enough sample so that common attributes can be identified. It is possible to study what properties enable one to become an "elite" or outstanding runner. However, this sample cannot be considered representative of the "average" runner.

Set C is the most well-distributed sample and will give the best idea of the range of abilities and accomplishments. However, there is little physiological information available on most of the runners, so work will be handicapped by insufficient data.

Set D is a sample containing only average runners. Thus it cannot truly represent the range of abilities available. One may not learn why people are <u>good</u> runners, but it is possible to identify common characteristics of people who run marathons.

The point of this digression has been to address some of the advantages and disadvantages of various sample selection techniques and to show that this selection dictates which questions can be attacked. The same philosophy can now be applied to radio structure surveys. In a list of 10,000 radio sources, one may think of studying the following sets of objects:

A') Cygnus A
B') The 100 apparently strongest sources
C') Every 100th source, ranked according to flux density
D') The 5000th - 5099th strongest radio sources.

The analogy with the runners is clear, and it is now possible to address a variety of questions by selecting from among the above choices. In many cases, some suitable combination of B' and C' will be most appropriate. The point of this entire philosophical discussion can be summarized in the following statement:

<u>Axiom</u>: You must decide not only which sample is most representative of an entire class, but also which aspects of that class you wish to study, before making a final selection of sources.

II. Source Selection

The general method of choosing radio sources for a structural survey is to pick a set of sources from one of the many flux density ~~surveys~~ surveys in the literature. A few of these surveys are listed in the Appendix.

One option is to choose a flux-limited sample; that is, map every source above a given flux density. The observer may choose a high limiting flux density and look at sources over a large part of the sky. Alternatively, a lower limit may be used in order to make a deeper survey over a small portion of the celestial sphere.

The frequency at which sources are selected is crucial. Selection from the 178-MHz surveys will tend to give more extended radio galaxies, whereas a list of sources from a 5000-MHz survey will be more heavily weighted in favor of flat-spectrum quasars.

A distance-limited sample might give a more accurate representation of all radio sources in a given volume. However, the completeness of the sample then becomes a major issue that must be dealt with.

Another type of survey would involve the radio structures of sources identified only with a certain type of optical object. One can choose quasars, BL Lac objects, radio galaxies, Seyfert galaxies, or optically unidentified sources.

Objects first identified in surveys outside the radio band may be mapped. For example, optically discovered quasars or quasars discovered by the Einstein X-ray satellite may be studied. Studies of objects found in future infrared surveys may also be promising

Finally, a random assortment of objects may be mapped as long as the observer realizes that valid statistical conclusions cannot easily be drawn.

III. Goals

The immediate goals of a survey of source structures are the establishment of correlation between radio morphologies and other properties of radio sources. Some of the correlations which may be investigated are listed below:

1) Radio morphology with optical identification.
2) Radio morphology with radio luminosity.
3) Radio morphology with spectral index.
4) Radio source axis with optical axis of galaxy.
5) Radio structure with distance/look-back time.
6) Radio morphology with optical line emission.
7) Radio morphology with X-ray or infrared emission.
8) Radio structure as a function of environment.

Of course, these correlations are only preliminary steps to the understanding of the physics of extended radio sources. Perhaps the ultimate goal is the understanding of the energy production and supply mechanisms. In addition, structure surveys may be used to do astrometry, set up a reference system for navigation, and other such tasks.

IV. Results

Previous results of radio structure surveys can be divided into two categories. First, there are the "well-known" results, those which have been believed for many years without necessarily being attributable to a specific survey. These results often suffer from important selection effects. Second, there are the conclusions drawn about various aspects of source structure from specific surveys.

Some of the well-known results are as follows:

1) 60-90% of extended sources are doubles or triples (e.g., Miley 1980, A.R.A.A., 18, 169)
2) The strongest radio galaxies are collimated doubles (e.g., Fanaroff and Riley, 1974, M.N.R.A.S. 167, 31P).
3) Extended sources have steeper spectra than compact sources.
4) Complex (e.g., head-tail) sources occur predominantly in clusters of galaxies.

Two recent efforts at structural surveys have been made from the 178-MHz 3CR survey and the high-frequency 'S' and Parkes surveys. The 3CR survey includes a sample of 166 sources having 178-MHz flux densities above 10 Jy. These objects (declination ≥ 10°) have been mapped with the Cambridge 5-km telescope (Jenkins, Pooley, and Riley 1977, Mem. R.A.S., 84, 61 and references therein).

Hine and Longair (1979, M.N.R.A.S., 188, 111) studied the members of the above sample which were identified with galaxies having measured redshifts. They found that more than 90% of the galaxies having strong optical emission-line spectra were identified with classical double radio sources. On the other hand, those galaxies without strong emission lines had all types of radio structures.

Hine and Longair concluded that the original structure in the nucleus was maintained for the entire lifetime (> 10^7 years) of the most powerful double radio sources. They inferred that only the most massive galaxies reached a steady state in which the nucleus continuously supplied a steady amount of power to the radio lobes. By contrast, the Seyfert galaxies are not massive enough to reach such a state, so they have strong emission lines without the extended double sources.

Ulvestad et. al. (AJ, July 1981) used high-frequency flux density surveys to select all sources having flux densities above 1 Jy at 5 GHz (declination ≥ -45°). They found the following results:

1) Only 17% of radio galaxies are unresolved at the arcsecond level, whereas 65% of quasars are less than 1 arcsecond in size
2) The unresolved radio galaxies have much steeper spectra than either the resolved or unresolved quasars. They concluded that, in general, the galaxies did not have a strong self-absorbed core.
3) About 3/4 of the resolved quasars had more than 50% of their flux in an unresolved component, while less than 1/3 of resolved radio galaxies had a similar fraction of their flux in a compact component. This result supported the conclusion drawn from result #2.
4) The more distant quasars ($z \geq 1$) are less likely to be resolved than nearby quasars and have intrinsically smaller radio sources.

Note that because of the high-frequency surveys from which sources were selected, this latter work includes a much higher percentage of quasars than would be found in the 3CR sample.

Appendix

Flux Density Surveys

Survey	Frequency	Flux Limit	References
3CR	178 MHz	9 Jy	Mem. R.A.S., 68, 163 (1962).
4C	178 MHz	2 Jy	Mem R.A.S., 69, 183 (1965). 71, 49 (1967).
Bologna	408 MHz	0.25 Jy	Astr. Ap Suppl., 1, 281 (1970). 7, 1 (1972). 11, 291 (1973).
Westerbork	1415 MHz	~0.006 Jy	Astr. Ap. Suppl., 25, 453 (1976).
Parkes	2700 MHz	0.7 Jy	Aust. J. Phys. Ap. Suppl. No. 46 (1979) (Part 14).
NRAO-Bonn	5000 MHz	0.6 Jy	A.J. 83, 451 (1978) (New section out soon)

General Reference: IAU Symposium No. 74, *Radio Astronomy and Cosmology*, § I, pp. 1-81 (1977).