PROGRESS, PROBLEMS and PRIORITIES: A PERSONAL VIEW

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INTRODUCTION

Half a century after Hubble expansion was recognized and a quarter century after the identification of Cygnus A we must acknowledge that progress in observational cosmology is slow, the efforts are laborious, corrections are subtle and correlations elusive. Part of progress is the realization that there are no short-cuts, no easy methods or quick successes. The result of this awareness has been increasingly careful attention to the completeness of samples, to selection criteria and the hazards of intercomparisons from survey to survey. This week in Cambridge has shown both modest progress and progress in modesty.

There has been little or no discussion of cosmology in the restricted sense of space-time structure. Nor was there a lot of astrophysical analysis in this symposium. Mostly it was a symposium in the *phenomenology* of extragalactic radio sources; and quite properly so. This population, a violent constituent of the universe, is extremely diverse, spanning wide ranges of luminosities and sizes, *a fortiori* of emissivities; it shows a great variety of morphologies and of optical to radio coupling. Several properties, such as luminosity, size and duration, are plausibly suspected to depend on cosmological epoch in an evolving universe. It is necessary then to acquire very large source samples and very detailed multi-spectral data sets in order to unravel the suspected epoch-dependent relations and the inevitable selection effects. Slowly the dynamic range of source count fluxes and size count angular diameters becomes comparable to the characteristic width of the luminosity and linear size distributions.

Nearly two decades ago, in a brilliant analysis summarized in I.A.U. Symposium no. 9, Martin Ryle stated some essential conclusions based on early radio source counts, on the Copernican principle and the then available sky brightness limits. There were only nineteen extragalactic radio source identifications then and they were not essential to Ryle's arguments. He stated: "It ... seems very probable

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that most of the radio sources belong to a class for which $P > 3x10^{25}$ watts $(c/s)^{-1}$ $ster^{-1}$, ..." and: "If further observations confirm the present conclusions, the contribution of radio observations to cosmology will become of great importance." Ryle went on to illustrate this importance by showing how awkward even then the counts were for the steady state cosmology. In the discussion his opponents had to invoke an unknown galactic halo population to avoid these conclusions.

Martin Ryle in 1958 advocated more surveys, more measurements of angular diameters, further analysis of optical observations and 21 cm absorption-line measurements. It is clearly appropriate to discuss the subject here, in the new Cavendish Laboratory, to see how far we came and where we ought to go.

SURVEYS; ANISOTROPIES

That there is much progress in quantity, quality, spectral range and flux density-reach of surveys is evident from the first half dozen papers in this volume. Some nagging problems remain: bright source surveys are incomplete for large (say $\Theta > 100''$ arc) angular size sources; flux density scales do not match perfectly; there are declination-dependent calibration errors and resolution corrections to worry about; earth-rotation synthesis telescopes have resolution and flux-corrections which are still partially discordant. These problems need further attention from several teams. A careful reviewpaper of all surveys containing, say, more than 100 sources, describing their scope, content, quality, selection bias, etc. would be very helpful at this stage and would serve their use, diminish their abuse, for statistical purposes.

For several reasons, among them the spectral-index-dependent V/Vmax tests, it is of great importance to perform a substantial survey with a very sensitive large antenna at a high frequency, say $\sim$ 15 GHz. So far we have been in either the transparent domain ('steep spectrum sources') or the partially opaque domain ('flat spectrum sources', a substantial fraction of the 5 GHz survey sources). At 15 GHz we may expect to nearly complete the transition from transparent to opaque and to find a substantial number of ultracompact ('inverted spectrum') sources. These are also of great interest for further X-ray and optical work. The superb 100 m Bonn/Effelsberg telescope seems ideal for this high priority task.

The search for anisotropies or non-Poissonian characteristics in the distribution of survey samples or well-defined subsets continues. There are several teasing effects on the 2 to 2.5 σ level, but so far none are convincing of a universal anomaly. I do not advocate ignoring the anomalies found, although in the past equally intriguing effects have gone away when the samples were enlarged. (An example is the very flat integral source counts for part I of the Parkes 2700 MHz survey.) The anomalous subsample can be isolated, remeasured at other frequencies, identified optically. Thus can the nature of e.g. source number excess

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be understood. The tremendous range of luminosities results in a great interval of z being contained in a single sample of small flux density interval. Since it is obvious that particular cosmological non-uniformities, if there be any, are likely restricted to small redshift intervals, it is clear that count and spectral index anomalies are best evaluated by adding optical information to the set of data.

For the same reason, the great width of the luminosity distribution, radio source counts do not lend themselves for the determination of stringent isotropy limits. Nevertheless, as is summarized in Webster's paper and is corroborated by limits on microwave background anisotropies, we have no emperical evidence now that the universe does not conform to the cosmological principle. Appealing to the criterion of simplicity it is justified therefore to work with homogeneous isotropic world models for interpretive purposes, for the time being.

Apart from the high frequency survey advocated above, and the value of a low frequency survey sensitive to low surface brightness objects of large angular size such as reported here by Baldwin, one may question the need for further surveys. The discussion is not urgent in practice, because the earth rotation aperture synthesis radio telescopes survey inevitably. In the course of the next several years for example the Westerbork telescope alone will map hundreds of $\sim 1^{\circ}$ diameter fields all over the Northern sky, with flux limits at the 1 mJy level. These samples, fringe benefits of other programs, provide a data reservoir that lends itself to diverse statistical tests and contains source material for deep optical identification and redshift efforts.

OPTICAL IDENTIFICATIONS

In this area of our symposium's concern, progress has been most impressive. This is due to (a) the $\lesssim 1''$ arc positional accuracies provided by the several interferometers, (b) the accurate tie-in of optical and radio astrometric frames and (c) the very deep plates provided by both image tubes and, especially on the 4 m Mayall telescope at Kitt Peak, by direct photography.

The problem of misidentification due to random coïncidences in large radio-position error boxes is a thing of the past. (In the Southern Hemisphere the new Fleurs synthesis radio telescope can now provide $< 1''$ arc positions for Parkes and Molonglo survey sources where the identifications may be in doubt; a systematic effort to establish the statistical reliability of the thousands of identifications might well be undertaken there for the sake of economy of optical telescope time). A new problem arises to take the place of the old identification confusion. Combining very sensitive radio surveys with very deep plates leads to inter-galaxy angular distances of the same order as or less than the radio sources' angular sizes. Especially for very faint objects, where large z is suspected and many hours of spectrophotometry are called for, this is a problem. It was illustrated by the spontaneous discussion on the final day of the symposium concerning 3C 303. The way to overcome the problem is not to rely upon a radio centroid position, but to use a synthesis telescope that combines good angular resolution (< 3" arc) and dynamic range (better than 20 db) with the best point source sensitivity. Detecting the central source in doubles, coincident with the optical object, can remove all identification doubts. The 5 km telescope, the Westerbork SRT and the VLA, each with a different mix of these qualities, will solve most such problems north of -30^{o}.

An important condition for further progress is effective collaboration between optical and radio observers. Some systematic exchange of information on deep fields and plates of outstanding quality, perhaps in an IAU bulletin, seems overdue.

RADIO SOURCE COUNTS; SPECTRAL INDEX DISTRIBUTIONS

The contribution by Willis et al. and the review by Wall demonstrate the depth and the spectral range, source counts have now attained. Such counts played a very important rôle when nearly two decades ago the prime cosmological question was: 'does the Universe conform to the 'Perfect Cosmological Principle', i.e. is it represented by the Steady State model, yes or no?' As mentioned in our introduction, the early counts pointed to a decided no, although they left many sceptics till the microwave background discovery in 1965. The next simple question: 'if the Universe be represented by a Friedman cosmology, then is it open or closed?' is not amenable to simple tests by the use of radio source counts. Epochal population evolution overwhelms geometric distinctions and the source counts now play a rather different rôle: given a specified cosmic evolution of radiation and matter density, what can the source counts teach us about radio source formation and evolution, and thus indirectly about the formation of galaxies and their active nuclei.

Questions of the type just raised can only be pursued by combining a lot of radio and optical data. Of particular importance is the completeness of 3 CR and of its identifications. From it comes the local luminosity distribution. Together with the source counts it can be used to specify various z-dependent source population evolutions. These then generate predicted distributions of redshift and apparent magnitude as a function of flux interval, predictions that can in principle be tested.

The various spectral index distributions shown at this symposium are most remarkable for their lack of flux density dependence over considerable ranges of S, ranges large enough for the z- and P-distributions to change markedly. It is striking, even disturbing, given the presumed universality of the microwave photon flux, that there is no evidence of radiative loss spectral steepening for even the deepest samples! In the different $g_{\nu}(\alpha)$ distributions shown there are

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some S-dependent effects (see e.g. Jauncey et al., 1972, Astron. J. and Pauliny-Toth, Maslowski, this volume) which require further investigations. Similar remarks as were made above for possible anisotropies apply to these situations. Clearly the different source count results and the $\alpha(\nu_i,\nu_j)$ distributions can be tested for compatibility, including radio K-corrections, using programs of the generality described by Wall.

LUMINOSITY FUNCTIONS

Impressive progress was reported in this area, witness especially the paper by Perola and Fanti. Great statistical improvements, careful complete sample selection, an extension of the radio luminosity distribution to much lower powers and redshift data for ellipticals over a large range of absolute luminosities constitute these advances. The fact that the RLF has a very similar shape for different bins of ΔM_V, yet scales strongly in amplitude with M_V, appears of fundamental importance. That cluster and non-cluster populations are not distinguishable in this respect provides additional clues concerning the physics which couples stellar populations to activity in stellar system nuclei. So does the relation of the radio core power to absolute magnitude. Clearly the extension of this work to more comprehensive samples and the concentration of theoretical investigations upon the relations found thus far deserve high priority. It is unfortunate that the program could not provide more time for these modern perspectives this work provides. The reorientation of the subject is ahead of the symposium program!

The quasar luminosity distribution overlaps with that of radio galaxies only at the high power end where the space density is so low that a current epoch RLF is not defined. There are two items concerning quasars as a population upon which I wish to comment. One is the m-z relation presented by Bahcall and Turner. We are used to see this relation for the brightest ellipticals in clusters and for strong radio galaxies. We easily forget that these relations are in fact envelope curves for all other ellipticals, not shown, at lower z for a given m-value, i.e. rather like Figure 1 in Bahcall's paper but with better statistics. The Hubble diagram for quasars provides a well defined relation, one which is expected in the so-called conventional redshift interpretation. The 'non conventionalists' have yet to accommodate this relation.

Another noteworthy item is Schmidt's V/V_{max} test for flat spectrum quasars from the NRAO 5 GHz survey. Contrary to steep radio spectrum quasars and to optically selected ones whose $\langle V/V_{max}\rangle \sim 0.65$, indicative of a strongly epoch dependent LF, the flat spectrum quasars give a value ~ 0.5 which in naive parlance is referred to as the Euclidian value. My view is that the rather lower value of V/V_{max} for this sample poses an interesting problem of epoch-dependent astrophysics. Steep spectrum radio sources radiate from large volumes of low optical depths at radio frequencies. Optically selected and flat spectrum quasars radiate from ultra compact regions with moderate to high opacity at radio frequencies. Schmidt's result may imply that

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optical photons and relativistic particles can get out of the quasar over a large z range, but radio waves encounter greater (possibly free-free) opacity in the compact region at earlier epochs. The flat spectrum quasars are then relatively suppressed. We need to survey at higher frequencies, that is lower opacities, to recover them.

To further understand the radio to optical coupling the determination of the function Ψ (R) (see Perola and Fanti) is important. For this purpose more apparently-bright quasars need to be found, one of several reasons why an unbiased optical survey such as the one going on at Caltech is so valuable.

ANGULAR DIAMETER TESTS

Radio source number counts have gone very nearly as far as they can. As mentioned above they can provide limited additional insight for physical cosmology and then only in conjunction with difficult optical work on very faint samples. An alternative, in fact complementary pursuit is the determination of angular size distributions of complete samples as a function of limiting flux and/or as a function of redshift. Especially Swarup and Kapahi at the Ooty Observatory have in recent years explored and fruitfully posed the method of angular size counts. Their work and related efforts at Jodrell Bank and Cambridge initiated what promises to be a broad multi-observatory programme using aperture synthesis and intermediate baseline interferometers as well as lunar occultation radio data to be matched by optical identifications and redshift determinations. The observational bottleneck will be optical rather than radio telescope time. In the course of the next decade the structure of the N(S, Θ, z) distribution function will slowly emerge. When it does, will it be interpretable?

There are two snags: one is the astrophysics of the hot spots in the lobes of the strong symmetric double sources. Hewish suspects them to have a tolerably low intrinsic linear diameter dispersion. The challenge is to learn the formation and dissipation processes of these bright but radio synchrotron-transparent regions. Particularly, is that evolution independent of epoch-dependent environmental conditions? If not, is it predictably dependent or will physical reality again hide geometric distinctions of alternative cosmologies? Here and elsewhere Roeder has emphatically drawn our attention to the other barrier facing angular size counts interpretation in terms of geometric cosmology. It may well be that such a laboriously acquired set of data in the end tells us something about density contrasts distribution while the elusive q_o slips through our fingers once more. But that too is cosmology.

OPTICAL SPECTROPHOTOMETRY

Of all progress evident at this symposium, results reported by Boksenberg and by several other workers, especially from Lick Observatory stand out. Brightest galaxies now can have their redshifts measured

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even if $m_V > 21$; Minkowski's old z-value record for 3C 295 has been broken in half a dozen cases and we may expect the z = 1 mark to be passed soon. Devices of high quantum-efficiency and good stability enabling accurate sky-subtraction are slowly finding their way to the domes of large telescopes. Since the number of telescopes with apertures exceeding 3 meters is increasing from three to at least nine in this decade, and since each of them will presumably be equipped with one or more of these near-optimum devices, we are entering a new era of observational cosmology. It is clear that there is every opportunity for radio and optical astronomers to work as fruitfully together in the near future as in the recent past. As I said earlier, optical telescope time will continue to be the scarcest item: even with coarse spectral resolution just sufficient for a z-determination, photons per pixel from a twentysecond magnitude galaxy are few and far between. It is all the more important then that when the best dozen optical telescopes are engaged for radio source studies, the most accurate and reliable radio data sets from well defined complete samples be used as source material. Such samples, from 3CR levels to eight magnitude deeper are now becoming plentiful.

At very great spectral resolution the new spectrophotometers show the wealthy detail of emission and absorption line spectra of quasars and of active nuclei in galaxies. Data are needed for many strong radio sources, for Seyfert and Markarian galaxies. The energy transformations there pose perhaps the most challenging problem of modern astrophysics. Radio VLBI observations and simultaneous multifrequency variable source monitoring as well as X-ray data hoped for from HEAO-B will supplement the optical spectrophotometry.

Opaque radio components in galactic nuclei are the most telling indicators of *current* activity. Radio detections of central components in already identified double sources as well as in Markarian galaxies being discovered in the ongoing objective prism surveys should be systematically attempted. Such programs will help to select the most promising objects deserving costly spectroscopic investigation. Exchange of observing plans and early results, between teams working in different regions of the spectrum, will enhance the chances for progress.

IN CONCLUSION

In one of the final papers of I.A.U. symposium nr. 9 McVittie said: "In my view of cosmology, observation enables us to reject certain classes of models but it does not permit us to pinpoint some particular model among those that remain". At the end of this symposium that view is reaffirmed. Even narrowing the options is difficult but remains an exciting enterprise. Exciting not only because cosmology has held a fascination worthy of hard labour since the dawn of scholarship. But rewarding also because its pursuit ever leads to surprising new objects and to processes we did not anticipate in astrophysical reality.