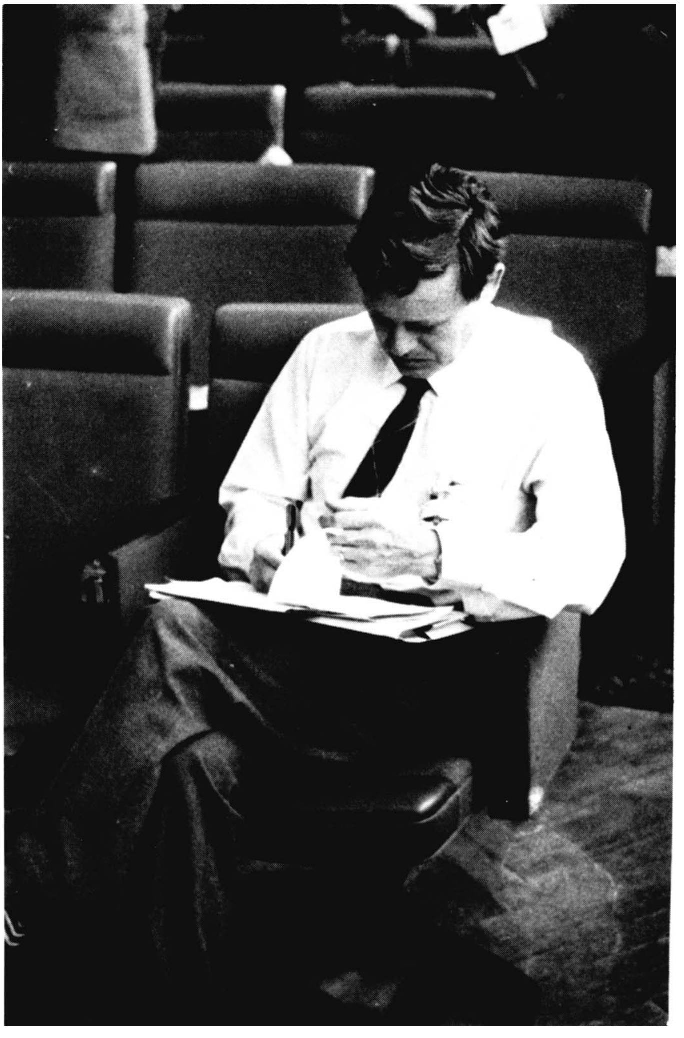
SECTION I

SURVEYS OF ACTIVE GALAXIES AND QSO'S

https://doi.org/10.1017/S0074180900154841 Published online by Cambridge University Press



It's a heavy responsibility to give the first talk!

LISTS OF ACTIVE GALAXIES, PROBLEMS OF DETECTION AND STATISTICS

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ABSTRACT. The various techniques for discovering active galaxies are reviewed, the main emphasis being on optical techniques and their application to emission-line galaxies with active nuclei. The three principal sets of selection criteria involve morphology, colours and emission lines. The major extant lists of emission line galaxies are summarized. Problems of detection are discussed, including selection effects and the use of automatic plate measuring machines. The difficulties of generating useful statistics on different classes of objects are highlighted, but no attempt is made in deriving new statistics or to summarize those in the literature.

1. INTRODUCTION

This Symposium owes a great deal to the pioneering work of V.A. Ambartsumian, one of the first astronomers to draw attention to active galaxies and to the astrophysical problems which they raise (e.g. Ambartsumian, 1965). It is also particularly appropriate that the meeting is being held in the Byurakan Observatory, where the late B.E. Markarian carried out his monumental survey for active galaxies and inspired many astronomers here and elsewhere to continue his work.

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E. Ye. Khachikian et al. (eds.), Observational Evidence of Activity in Galaxies, 3–16.

There are three main classes of "active" galaxies from an observer's point of view. The simplest are mostly nearby galaxies showing unusually high levels of star formation, either in their nuclei or in giant HII regions; the second are Seyfert-type galaxies with nuclei often showing evidence for non-thermal radiation, although equally in many cases it can be argued that what is seen is an exceptionally active star forming region or "starburst" nucleus; the third are quasars where a non-thermal nucleus is totally dominant. The most common optical properties in all three classes are strong emission lines and a strong ultraviolet continuum. Of course there are no clear divisions between these types, nor unambiguous definitions of the classes. Many galaxies are classified differently using different data or observing techniques, or simply by different astronomers using the same data. There seem to be at least two underlying physical explanations depending essentially on whether the source of the activity is ordinary star formation or the still not fully-understood quasar mechanism. Star formation in turn seems to occur in a variety of ways, while it is not yet possible to decide whether all types of non-thermal activity are due to a single mechanism such as an accreting black hole.

This review will be concerned primarily with the different ways in which active galaxies can be recognised, and will concentrate mainly on the middle category of "galaxies with active nuclei" or AGNs, since there have been other recent symposia on star formation and on quasars. Although astronomers are driven by the desire to understand astrophysics, and hence one might expect searches to be directed towards solving some of the problems indicated above, in practice there are also other factors. Many searches have been stimulated rather by the availability of a particular technique, or because active galaxies are relatively easy to find and make good subjects for follow-up studies, or perhaps just because they are intrinsically exciting objects to observe. This may sound unduly critical or cynical, but it is simply a fact and helps to explain why it is very difficult to make statements about the statistics of active galaxies. Rather than defining classes of objects and then setting out to find complete samples, sometimes one finds heterogeneous samples of interesting objects and then tries to classify them.

Two general points are relevant here. First, in another recent conference proceedings Kinman (1984) has given an excellent illustrated review of search techniques for emission-line galaxies, and many other useful illustrations are given in a recent "atlas" of objective prism spectra by Savage et al. (1985). Second, the author wishes to apologise for the incomplete nature of this paper, and in particular to the many astronomers whose relevant work is not cited; the disruption caused by a move at the critical time means that it is not the comprehensive review which had been intended.

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2. SEARCH TECHNIQUES

Several independent optical techniques have been used to search for active galaxies, the principal methods being by morphology, colours and the direct detection of emission lines. Lesser used techniques include optical variability and polarization. In addition large numbers of active galaxies have been recognised first at other wavelengths, ranging from radio to X-rays.

2.1 Optical Morphology

Three distinct criteria have been used: the presence of very compact cores, evidence for interactions or other disturbances, and high overall surface brightness. The study of compact galaxies was pioneered by Zwicky, the most comprehensive surveys being his own (1971) and, in the southern hemisphere, by Fairall (1984). Although it is obvious from casual inspection that some galaxies have much stronger and more compact cores than others, it is not easy to make a quantitative definition of compactness. Some galaxies certainly have quasar-like nuclei which are always unresolved, but in general the apparent compactness of a galaxy core is a function of the plate scale and focal ratio of the telescope used; even for the same telescope, photographic plates taken in different "seeing" or with different exposure times will yield different samples of compact galaxies. An example of these effects is given by the pilot study of Allen et al. (1978), who searched some of the first fine-grain Kodak IIIa-J plates taken on the UK Schmidt Telescope (UKST) and compared their results with the classical work of Zwicky. The better resolution of the UKST plates resulted in the selection of galaxies which were systematically fainter and more distant than the Zwicky galaxies, but which seemed in other respects to be exactly the same class of objects. Most of these "compact" galaxies are not particularly remarkable and are not active, but the lists do include emission-line galaxies and some Seyferts.

Atlases of interacting and peculiar galaxies have been published by Vorontsov-Velyaminov (1959) and Arp (1966), and a systematic search by Arp and Madore of the UKST IIIa-J plates of the ESO/SERC Southern Sky Survey should be published soon. The Morphological Catalogue of Galaxies (Vorontsov-Velyaminov et al. 1962-74) includes many peculiar and nucleated galaxies, while many active Southern systems are included in the ESO-Uppsala survey (Lauberts, 1982) and have had follow-up spectroscopy done by West and his collaborators. Many Southern systems have already been included in the ESO-Uppsala survey (Lauberts, 1982) and follow-up spectroscopy has been done by West and his collaborators (e.g. West et al. 1981). Catalogues such as these are usually even less homogeneous and the selection criteria less quantifiable than those of most other techniques. However they are certainly fruitful sources of unusual galaxies which are active in the sense of having exceptionally high levels of star formation activity. For example, NGC 5291 seems to be one of the largest and most massive galaxies known (Longmore et al. 1979), the "Carafe" group includes a Seyfert 2 galaxy and a narrow emission line galaxy (Hawarden et al., 1979) and many other interacting systems show evidence for recent star formation both in the nuclei of the galaxies and in outlying knots. It is generally believed that these are all examples of star formation and nuclear activity being triggered by a gravitational interaction, either through the accretion of material on to an existing nucleus or through the compression of material in the outer parts of the galaxies.

Galaxies with unusually high surface brightness to some extent overlap the compact galaxies mentioned above, but this technique has been applied to nearby resolved galaxies by Arakelian (1975) and recently by Phillipps and Disney (1986) and again yields samples of galaxies which are particularly active in star formation.

2.2 Colour Criteria

The various colour criteria used nearly all amount to ways of detecting a very strong optical ultraviolet continuum (UV excess or UVX), indicating either large numbers of massive hot young stars or non-thermal quasar-like activity. However recently some very high redshift quasars ($3.5 < z < 4.1$) which have virtually no ultraviolet emission have been identified by their unusual colours in the red part of the spectrum, due to the redshifted location of strong emission lines.

For quasars it is possible to use only two colours, typically U-B, in order to identify many (but by no means all) candidate objects. However the most widely-used technique as applied to galaxies depends on taking triple-exposure photographic plates through a succession of filters and displacing the image slightly between each exposure. The exposures are chosen so that the three images are approximately balanced or show some characteristic pattern for most "normal" galaxies; UVX objects then stand out on visual inspection of the photographs. This technique was pioneered by Haro (1956) and Haro and Luyten (1962), and used by Mitchell et al. (1982) and most recently and extensively by the Kiso Schmidt Telescope group in Japan (KUG: Takase, 1980; Noguchi et al., 1980; Takase and Miyauchi-Isobe, 1984-86). In follow-up spectroscopy of a sample of 55 KUGs, Maehara et al. (1986) find that 80 percent show emission lines typical of giant HII regions and bursts of star formation.

A second method uses slitless objective prism spectroscopy instead of multiple exposure plates. UVX galaxies are then recognised by their abnormally long spectra, extending down to the atmospheric cut-off. This is essentially the method used by Markarian and his collaborators (Markarian, 1967; Markarian, Lipovatskii and Stepanian, 1983; Kazarian, 1979; see also Pesch and Sanduleak, 1983). Great care is needed to ensure that an ultraviolet tail represents a true UV excess and is not simply due to an intrinsically bright nucleus; for example, in his early work Markarian (1967) used English Kodak plates which had a fortuitous dip in sensitivity in the green part of the spectrum, and obtained a semi-quantitative criterion by comparing the relative strengths of the two halves of each spectrum.

2.3 Detection of emission lines

Slitless objective prism spectroscopy was used by Haro (1956) to show that some of his first colour-selected galaxies had strong ultraviolet [OII] emission, and some Markarian galaxies have emission lines as well as strong UV continua. However the first major survey where emission lines were the primary selection criteria is that done by Smith (1975) at Cerro Tololo. Results for one section of that survey were published by Smith et al. (1976), and similar extensive searches have been carried out in the south by MacAlpine et al. (1977) and in the north by Pesch and Sanduleak (1983). Many smaller-scale searches have been carried out on UKST objective prism plates, but in most cases emission line galaxies have been regarded as by-products of quasar searches; Hazard (1986) has recently given a comprehensive review of the work done by himself, Terlevich and McMahon at Cambridge.

The three very distinct types of extragalactic objects which are most easily detected on deep low dispersion UKST prism plates illustrate well the inherent problems of this type of search technique. These three main types are: (i) distinct HII regions in very nearby galaxies, showing a pair of emission features due to [OII] at λ 3727 and unresolved $H\beta$ + [OIII] at $\lambda\lambda$ 4861-5007; (ii) isolated slightly resolved objects showing the same pair of lines at low redshift ($z < 0.1$), and often called "extragalactic HII regions"; and (iii) stellar objects showing one, two or occasionally three emission lines at any point in the spectrum, i.e. quasars at a wide variety of redshifts. The basic problem is that the selection effects imposed by the limited dynamic range, wavelength coverage and spatial resolution of the photographic plates conspire to produce these three rather artificial and apparently distinct classes. In reality, presumably, examples of all three types of galaxies exist over a wide range of distances and intrinsic luminosities, and there must be many "intermediate" classes if not a complete continuum of objects. This again emphasises the difficulty of making meaningful statistical analyses of the relative frequency of different classes of objects. It is hard enough to derive useful statistics on the numbers of objects found in a given survey: it is almost impossible to go from these to astrophysically useful numbers on the relative frequency of occurrence of different classes in the universe.

There is a second way of detecting strong emission lines, which is really a variant of the colour method. Pairs of photographs are taken through adjacent narrow band filters, one on a line and one off, or through a narrow and a broad band filter both centred on the same wavelength. The advantage of this method is that it can be used to find fainter objects, since both the sky background and the problems of overlapping images are greatly diminished. The drawback is that only one line at one wavelength can be detected. A variant of this method is to take objective prism plates through an intermediate band filter to isolate a spectral region of interest;

this technique has been used to find galaxies with strong Hα emission by Kinman (1983) and by Moss and Whittle (in preparation).

2.4 Other optical methods

Many active galaxies and quasars are optically variable. This fact has been exploited by Hawkins (1986) to find faint quasars. It is much more difficult to apply the method to galaxies, at least on Schmidt sky survey photographs, since the variable nucleus is superimposed on an often dominant non-variable galaxy core and both components are then convolved with the atmospheric seeing and recorded on a non-linear detector. However a few famous extragalactic objects were already known as variable "stars" (e.g. BL Lac, AP Lib) and there may be scope for further discoveries, particularly using carefully calibrated data from automatic plate measuring machines.

Some active extragalactic objects, notably BL Lacertids, show strong optical polarization. However attempts to find new objects of this type by taking pairs of photographs or CCD images through polarizing filters have not yet had any confirmed success. The difficulty is that even in the most favourable cases the expected variations are comparable to the noise in the data.

2.5 Optical identification of sources at other wavelengths

A discussion of these well-known techniques is beyond the scope of this review. However our present great interest in active galaxies probably owes more to radio astronomy than to optical astronomy itself, starting from the discovery of quasars and N-galaxies and continuing today with the recent discovery of several of the highest known redshift objects. The X-ray surveys, especially those by the Einstein satellite, have added greatly to our knowledge of active galaxies and quasars, and much is expected of ROSAT. Recently the identification of infrared sources found by the IRAS satellite has been a very fruitful source of new active galaxies, especially Seyferts. These techniques will presumably be dealt with fully by other contributors. In the context of this review, perhaps the most important feature of surveys at other wavelengths is that they yield samples of objects free from some of the enormous selection effects which bias most optically-selected samples, although no doubt they introduce new biases of their own.

3. LISTS OF ACTIVE GALAXIES

As explained in the Introduction the following list is not claimed to be complete, and the order has no particular significance. Rather it is intended as a starting-point for newcomers to the field, by giving a brief résumé of most of the major published optical surveys for active galaxies (adopting here the relatively narrow definition which excludes both nearby galaxies with HII regions and distant quasars). It is also restricted to those surveys which were made specifically to look for active galaxies, and which include a hundred or more such objects. There are of course other enormous and very important catalogues of galaxies, such as those of Zwicky and Vorontsov-Velyaminov, or the major radio catalogues, but these are perhaps better regarded as source-lists for active galaxies since they also contain many other types of object. It is also impossible within the confines of this review to give all of the relevant references; for example the primary Markarian survey was published in a series of fifteen papers, and there are many other relevant papers dealing with follow-up spectroscopy of subsets of the samples, and with discussions of the nature of the objects catalogue.

TABLE I

Title	No. of objects	Area of sky (square degs)
Markarian "MKN" (Papers I-XV) (1967-1981)	1500	15,000
Byurakan II (Markarian et al. 1983 et seq.)	100	16
Kazarian (1979 et seq.)	600	
Kiso Schmidt "KUG" (Takase and Miyauchi-Isobe, 1984-86)	1100	650
Smith, Aguirre & Zemelman (1976)	116	700
Michigan/Curtis Schmidt (MacAlpine et al. 1977 et seq)	500	1,000
Case Low Dispersion (Pesch & Sanduleak 1983 et seq)	350	300
Fairall (1984) (confirmed objects)	130	5,000

In addition to these lists, there are catalogues of specific classes of objects. For example, Khachikian and Weedman listed 71 Seyfert galaxies in 1974; a recent catalogue by Kaneko (1986) gives 560 galaxies classed as Seyferts. The second edition of the ESO catalogue of Véron-Cetty and Véron (1985) lists 739 objects as AGNs and 236 Seyfert I galaxies, while Hewett and Burbidge are preparing a new catalogue of low redshift AGNs.

4. PROBLEMS OF DETECTION

4.1 The nature of the problems

There are really three separate problems involved in detecting active galaxies and quasars: first the classes of objects have to be properly defined, then candidate members of the classes have to be found, and finally their true nature has to be verified. Unfortunately even the first step has not yet been satisfactorily solved. Most searches so far have been based on empirical observational criteria, but without a proper theoretical understanding of the objects there is always a risk that intrinsically quite separate types will be lumped together because of apparent similarities, while apparently very different classes may be closely related. For example, it is still argued that the differences between various classes of radio galaxies and quasars are simply due to different orientations of beamed sources with respect to the line of sight.

Once a class of objects has been defined, a satisfactory search procedure requires quantitative measures of identifying characteristics or parameters. Most searches done up to now have relied simply on visual inspection of photographs, and the resulting lists are subject to strong selection effects as well as varying degrees of completeness.

A third problem is that of verification. To check that candidate objects really are quasars or active galaxies usually involves obtaining moderate dispersion spectra, and for large samples of faint objects this is very expensive in observing time on large telescopes. The recent development of multi-object spectroscopic systems, for example by using fibre optics to feed light from 50 objects into a single spectrograph (Ellis et al., 1984), promises to alleviate this problem.

4.2 Selection effects

The significance of selection effects is well illustrated by the example of visual searches for quasars on objective prism plates. This is at first sight a relatively simple problem, since many quasars have extremely striking and unusual spectra. However even here there are powerful selection effects at work, so that the technique has been aptly called "subjective" prism spectroscopy. First, there are three selection effects intrinsic to the quasars themselves: (i) magnitude, since on a given plate the spectra are only well-exposed over a range of about two magnitudes; (ii) redshift, since only a limited range of wavelengths is recorded on a given plate and this range will include strong emission lines for some redshifts but none at other redshifts; and (iii) line strength, since weak lines will be lost in the noise. Second, there are selection effects depending on plate quality (including "seeing" and background density), plate scale and prism dispersion. Finally there are totally unquantifiable effects such as the variable alertness of

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the observer, and the problem that no two observers will select the same set of objects on a given plate, since each person will use a different set of complex pattern-recognition criteria, often subconsciously.

Turning from quasars to emission line galaxies, the selection effects are even worse. As well as all of the effects discussed above, there are effects due to the extended and often complicated spatial structure of galaxies. Two identical active nuclei embedded in parent galaxies with different surface brightnesses and luminosity profiles will look very different, and have different probabilities of detection.

4.3 Machine detection techniques

Many (but not all) of the selection effects can be more easily dealt with using fast automatic plate measuring machines or microdensitometers, such as COSMOS at ROE and the APM in Cambridge. Their application to stellar images on multicolour direct plates is reasonably straightforward and is proving a very powerful way of selecting quasars. They can also be used to search objective prism, "grism" and "grens" plates. The machines yield quantitative data as pixel-by-pixel densities which can be converted to intensities. However the problems of calibration and pattern recognition are still very difficult and the analysis involves many steps and a great deal of sophisticated computing. Two schemes have been described in some detail by Clowes et al. (1984) and by Hewett et al. (1985).

The essential steps can be summarized as follows:

(i) Measure a direct plate.	Locate objects Eliminate overlaps Set wavelength zero-point Include objects with little continuum Do star/galaxy separation
(ii) Scan spectra on prism plate	Add adjacent scan lines Produce one-dimensional spectra (Note cannot do sky subtraction, but sky is featureless since no slit)
(iii) Convert to intensities	Remove intensity non-linearities Remove emulsion "bumps" (i.e. wavelength-dependent variations in sensitivity and "gamma")
(iv) Select candidate objects	Calculate S/N Look for real features (emission and/or absorption)

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Measure continuum shape
Measure line widths
Measure equivalent widths
Recognise patterns, or compare with templates
Determine redshifts

All of these processes have so far been applied only to quasars, and to some unusual types of stars. Application to extended galaxies is possible in principle but is clearly considerably more difficult.

Even with a machine search, the sample of objects selected is still obviously a function of the selection criteria. Thus one can perhaps set a machine to find most of the quasars in a field which have magnitudes and redshifts within certain (narrow) ranges, and line strengths above some limit, but we are still far from being able to set a machine to simply "find all the quasars". Furthermore since most objects are faint and their images contain only a limited amount of information, the best one can do is to set probabilities that a given object is a member of one class and not another.

5. STATISTICS

Ultimately, getting good statistics on the relative spatial frequency of different classes of objects, probably as a function of redshift, is the most important objective of searches for active galaxies and quasars. The two crucial parameters to be determined for any list of candidate objects are its completeness and reliability. The data can then be used to suggest and test theories of the nature and evolution of the objects. In view of all the practical difficulties and theoretical uncertainties already described, it is clear that these goals are probably not yet attainable. It is very dangerous to use published statistics without carefully checking how they were derived and to what they apply. Sometimes a statement that says 10% of the galaxies in a certain list are emission line galaxies should perhaps be regarded more as a definition of an emission line galaxy than as a statistic. Also, the lists of objects found are highly technique dependent, and often two lists of what are ostensibly similar objects in the same field have only a few objects in common.

There have been many analyses of the content of various lists of galaxies, giving the relative proportions of objects of different types, and those analyses are entirely valid and very useful. Nevertheless there is still a problem in comparing similar analyses of different samples of galaxies since the classification criteria may not be identical. Finally there are problems associated with the magnitude calibration of data, for example, in connection with the luminosity function and surface density of quasars. Few surveys have good photometric calibration at faint magnitudes, and apparent differences in discovery rates may simply be due to different magnitude limits cutting a steep luminosity function.

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However all this does not mean that the searches are a waste of time. There is obviously a feedback process whereby an increase in the understanding of the nature of active galaxies leads to a refinement of the selection criteria, which can be used in turn to generate new samples of objects and hence a further step in understanding their nature. Clearly the day of visual searches of prism plates is already past for most purposes, and future progress depends on machine searches and automatic pattern recognition algorithms. Meanwhile the present imperfect search techniques do lead to the discovery of rare and unusual objects from time to time, and these sometimes lead to spectacular breakthroughs in understanding; such discoveries are unaffected by statistical incompleteness but simply require very large samples. Questions such as whether or not active galaxies occur more or less frequently in clusters than in the field, or whether quasars exhibit the same sort of superclustering as do clusters of galaxies, can and are being answered with presently available or obtainable data. Certainly the subject is currently in a very exciting stage of development, with the numbers of known active galaxies and quasars increasing by an order of magnitude every decade, and new techniques leading to new discoveries almost every week.

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DISCUSSION

STEPANIAN: What is the percentage of Seyfert galaxies in different surveys: in Cerro Tololo, in Siding-Spring survey and in Kitt-Peak?

CANNON: I think it is difficult to give a meaningful answer the the question because of the selection effects I discussed. Most people seem to find that about ten percent of the emission line galaxies found in objective prism surveys are Seyfert galaxies.

HUTCHINGS: Can you comment on clusting of active galaxies with each other or other galaxies?

CANNON: This is very difficult because of the selection effects and unreliable statistics which I have discussed. There are some reports in the literature that emission line galaxies occur less frequently in clusters, but others find an excess of emission line galaxies in clusters.I think this must be because people are using different techniques and finding different kinds of objects.

ALLOIN: I would like to add that for the southern sky, the ESO Schmidt Survey has been partly searched for active galaxies. Several lists have been published (ESO objects). Astron. Astrophys. Suppl.

CANNON: Yes, of course. I knew that I would miss something important and I apologize. I assure you that this survey will be included in the published version of my talk.

OSTERBROCK: In the first object you showed (NGC 5291) do you have spectra that show that the apparent HII regions at large distances all have essentially the same redshift as the galaxy?

CANNON: Yes, they do. In fact there is a linear gradient of velocities across the whole system which can be interpreted as a rotation, and we also have HI radio data. The system is extremely large in both mass and extent. These data are not new but were published in a paper in Monthly Notices by Longmore et al. a few years ago.

PISMIS: I should think that the kinematics of galaxies, in particular of their central regions may also provide a criterium for activity in the nuclei of galaxies. As of to-day we know that there are quite a few that show expanding motions as well as some showing inward motions. This sort of situation is not a steady state one, and such galaxies do not enter into the conventional definition of active objects yet they are active galaxies.

CANNON: I agree completely. However it is difficult to find these objects from wide-field surveys for ultraviolet excess objects or from objective prism emission line surveys. I suppose they must be found using higher dispersion spectra of individual galaxies.

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TOVMASSIAN: In connection with the subjectivism on the compiling of the lists of galaxies with excess UV-emission I would like to comment that radio data definitely show the reality of it. Indeed the radio survey of about 500 Markarian galaxies of the first five lists with the 300 ft Green Bank dish at 6 cm resulted in the discovery of 26 radio sources. In observations of about the same amount of galaxies of lists 7-11 with the Effelsberg radio telescope at 11 cm we expected to detect radio emission from about 40 galaxies while only 15 radio sources were detected. Such discrepancy may be the result of difference in conditions of observations in searching of galaxies with UV-excess or it may be due to subjectivism in picking up such galaxies.

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