LOW-LUMINOSITY ACTIVE NUCLEI IN ELLIPTICAL GALAXIES

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ABSTRACT. The results of a sensitive radio and optical survey of nearby early-type galaxies show that most (perhaps all) bright ellipticals have 'active' nuclei. These are characterized by a central non-thermal radio source and a weak LINER-like optical emission spectrum. There appears to be a smooth continuity in optical and radio properties from the weakest nearby sources to strong radio galaxies. Galaxies with radio sources usually show optical emission lines, but there is no simple relationship between gas content and radio power.

1. INTRODUCTION

Prof. Ambartsumian reminded us in his address that the radio galaxies were the first 'active galaxies' to be identified. The most powerful extended radio sources are always associated with giant elliptical galaxies, and during the past ten years high-resolution radio maps have greatly increased our knowledge of their structure. Models based on the accretion of gas by a massive condensed object have suggested some explanations for the observed phenomena (Rees 1978, Blandford and Rees 1978 and references therein), yet we still understand very little about how radio sources form and evolve in galaxies. In particular, do active nuclei arise as part of the normal evolution of early-type galaxies or only as the result of some accident such as an interaction with another galaxy?

In this paper, I would like to address three main questions:

(1) How common is 'activity' in nearby E and S0 galaxies?

(2) How is this activity related to the gas content ('fuel supply') in the central regions of the galaxy?

(3) What are the minimum conditions necessary for activity to occur?

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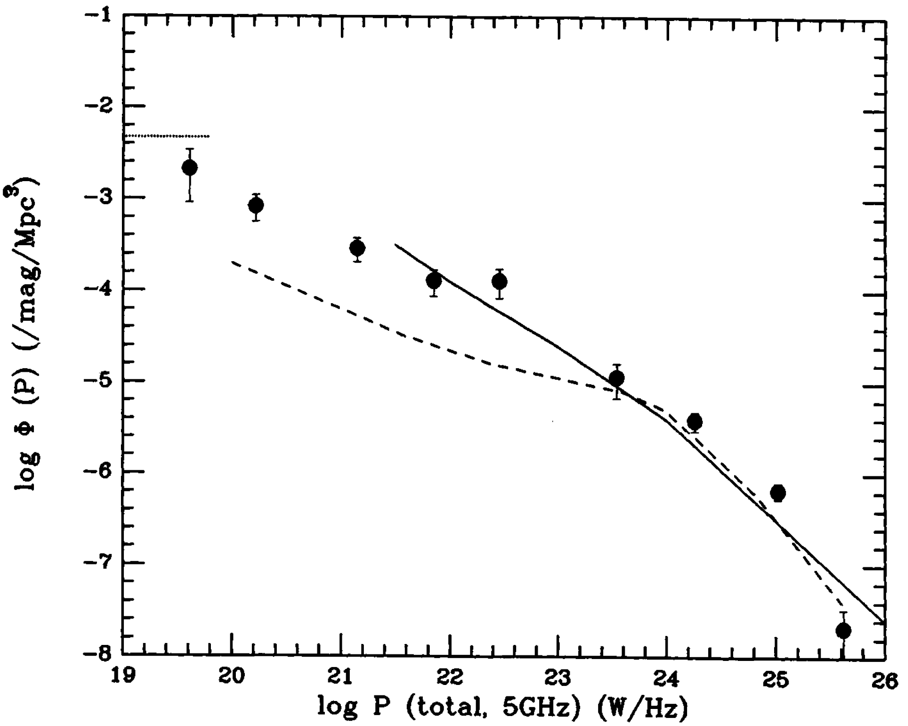

Figure 1: The radio luminosity function for E/SO galaxies. Previous derivations by Auriemma et al. (1977), (- - - -) and Windhorst (1984) (————) at lower frequencies have been shifted to 5 GHz assuming a mean spectral index of 0.7, and are shown for comparison. The dotted horizontal line at log Φ = −2.33 represents the space density of all E and SO galaxies brighter than absolute magnitude −18.

2. EVIDENCE FOR ACTIVITY IN ELLIPTICAL GALAXIES

We see at least two kinds of activity in nearby elliptical galaxies: non-thermal radio emission and LINER-like optical emission. The optical spectra of LINERs will be discussed in detail by Tim Heckman and Alex Filippenko, so I will only point out that most elliptical galaxies do show weak emission lines if one looks carefully (Phillips et al. 1986). Here, I would like to discuss some results from a recent radio survey of early-type galaxies.

Figure 1 shows a new determination of the radio luminosity function for E and SO galaxies at 5 GHz (Sadler, Kotanyi and Jenkins, in preparation), based on a complete, magnitude-limited sample of nearby galaxies combined with the Wall and Peacock (1985) all-sky catalog of strong sources. The space density of radio galaxies continues to increase at fainter powers, and below 10^{20} W/Hz approaches that of the entire population of early-type galaxies.

Taking a space density of $10^{-2.33}$ Mpc^{-3} for E/S0 galaxies brighter than $M_B = -18$ (Sadler 1982, $H_o = 100$ km/s/Mpc), at least 80% of bright, nearby ellipticals have a central radio source with $P > 10^{19.5}$ W/Hz.

We have little direct evidence of the nature of the weakest sources, since most were observed at a single frequency and are unresolved on scales of a few arcseconds. However, the continuity in radio power and morphology (with the radio jets in resolved sources becoming smaller and weaker as the total power of the source decreases) suggests that these sources arise in a similar way to their brighter counterparts - i.e. that most nearby ellipticals are weak radio galaxies.

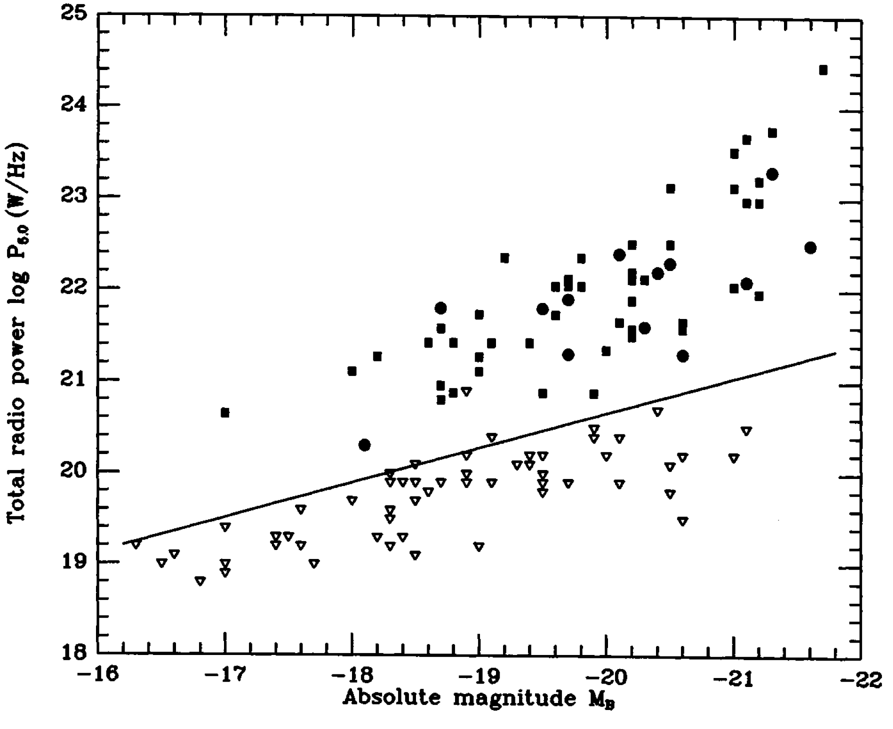

Figure 2: The relationship between radio power and optical luminosity.

If we look at the variation of radio power with optical luminosity (Figure 2), we find that the median radio power increases with bulge luminosity (as found by Auriemma et al. 1977), but that the **range** in radio power at any given optical luminosity is very large (at least 4 orders of magnitude). This suggests that at least one other parameter, in addition to the size of the galaxy, influences the radio power. Previous studies (Ekers and Ekers 1973, O'Connell and Dressel 1978) found that galaxies with central radio sources often showed [OII] emission lines, and in models such as that proposed by Gunn (1979) nuclear activity requires a steady supply of gas in the center

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of the galaxy. It is therefore interesting to reexamine the relationship between central gas content and radio emission, using the improved data now available.

3. GAS CONTENT AND RADIO EMISSION

Figures 1 and 2 are based on a complete, magnitude-limited galaxy sample in which the total luminosity M_B, radio power P_r and emission-line luminosity L_{em} (or upper limit) of each galaxy are known. Care is needed in investigating the relationship between these three quantities, as both P_r and L_{em} are correlated with M_B. By constructing the trivariate luminosity function, we find that galaxies with more luminous emission lines tend on average to have stronger radio sources at the same M_B. However, as shown in Figure 3, there is no direct correlation between radio power and emission-line luminosity (though all the elliptical galaxies with detected emission lines had radio emission at some level).

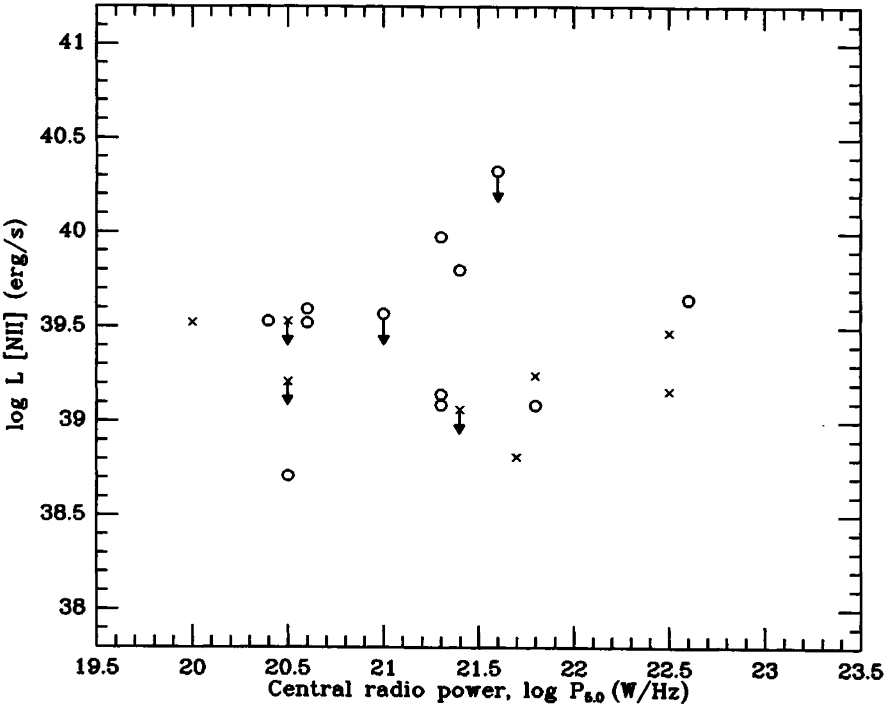

Figure 3: Comparison of the energy emitted in the [NII] emission line, and in the radio continuum by elliptical galaxies with central sources only (O), and with extended radio jets (X).

The results suggest that "some" central gas ($\sim 10^3$ $M_\odot$) is sufficient to produce a radio source in any bright ($M_B < -19$)

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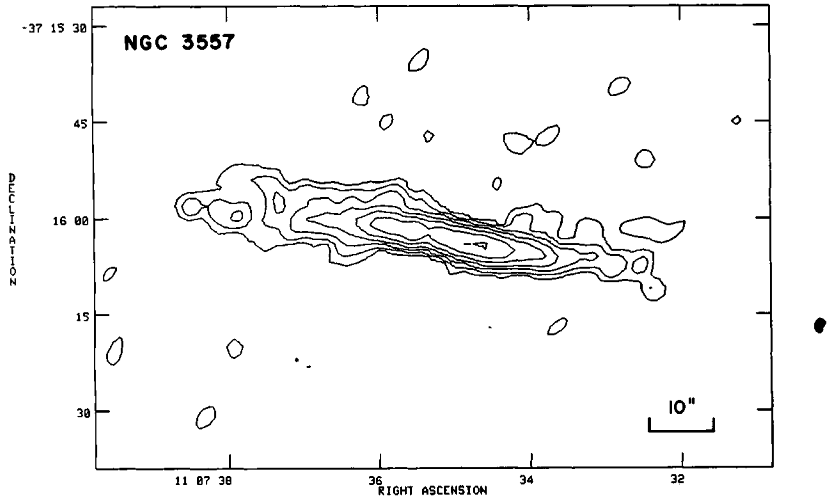

Figure 4: VLA map of NGC 3557 at 5 GHz, showing jets.

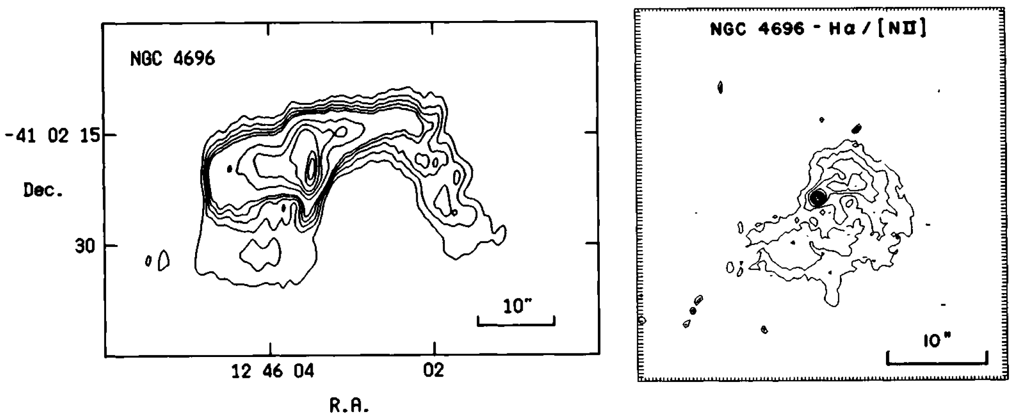

Figure 5: (a) VLA map of NGC 4696 at 1.4 GHz, made by R.A. Laing and C. Kotanyi. (b) Distribution of ionized gas in the center of NGC 4696, from Hα/[NII] CCD images. Other filaments exist further out, and the southernmost emission filament in this map is associated with a dust-lane.

elliptical galaxy. However, the **strength** of radio emission in an individual galaxy is not related to the galaxy's size and gas content in any simple way and there are some galaxies (such as NGC 1399) which have a radio source and no visible gas supply. It is possible that the radio power also depends on currently unobservable processes at work in the innermost few parsecs of the galaxy. For example, we do not know the kinematics of the gas inside a few hundred parsecs radius, and therefore have no idea what fraction of the observed gas ultimately reaches the nucleus itself.

Adding more gas to an elliptical galaxy does not seem to produce a stronger radio source, and indeed the presence of a substantial amount of gas may hinder the development of a "classical" radio galaxy. Figures 4 and 5 illustrate this in a more qualitative way. The two southern ellipticals NGC 3557 and NGC 4696 have similar absolute magnitudes and radio power, but NGC 3557 shows only very weak emission lines confined to its nucleus while NGC 4696 has stronger optical emission extended over a kiloparsec or more, together with a central dust-lane which probably contains some 10^6 $M_\odot$ of colder gas. While the radio jets in NGC 3557 extend over a region as large as the optical galaxy, those in NGC 4696 are stopped by the interstellar medium within 2 kiloparsecs of the nucleus. The density of the interstellar medium in the central regions of a Seyfert galaxy is considerably higher and, by comparison within Figure 3, Seyfert galaxies have a correspondingly larger fraction of their total energy in optical, rather than radio emission (Whittle 1985). Perhaps this is why spiral galaxies show activity in the optical and UV, and ellipticals in the radio.

I am grateful to Chris Kotanyi and Robert Laing for allowing me to show their unpublished map of NGC 4696.

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DISCUSSION

WARD: Would you like to comment on the agreement (or otherwise) of your results with those of other studies?

SADLER: Our work on the emission lines agrees with Caldwell's result that 40% of nearby ellipticals show weak [OII]3727 Å emission. As regards the weak radio sources, Birkinshaw and Davies also found a high detection rate of normal ellipticals at levels of 1mJy or so. Our results therefore seem to agree well with other recent studies.

WILSON: Following up on Ward's point, I think Dressel and O'Connell found a correlation between [OII] 3727 equivalent width and radio power in early type galaxies. a) Is your result different and b) does the form of the relation depend on whether the radio core is flat (self-absorbed) or steep (optically thin) spectrum?

SADLER: O'Connell and Dressel found that galaxies with a compact (flat-spectrum) radio source had a high probability of [OII] line emission, but that there was no correlation between [OII] strength and the luminosity of the compact source. The galaxies in our sample have radio powers typically an order of magnitude weaker than those studied by O'Connell and Dressel; but the results are broadly similar.

HECKMAN: Have you looked into the correlation between radio emission and X-ray emission from the elliptical galaxies in your sample?

SADLER: We have insufficient overlap with published X-ray data to look at this in detail.

YEE: How do selection effects in luminosity affect your radio-power versus absolute magnitude plot?

SADLER: The solid line in figure 2 shows the effective detection limit at the VLA. The correlation between median radio power and absolute magnitude was derived by constructing the bivariate luminosity function, and is not an artifact of selection effects.

BARTEL: What percentage of your galaxies have unresolved radio cores?

SADLER: All the detected galaxies have radio cores smaller than a few arcseconds. At least 30% also have an extended radio component.

MELNICK: Presumably the star formation rate in the central regions of elliptical galaxies will be much lower than say in spirals or irregulars. Do you think the supernovae from these stars could produce the types of activity you observe in ellipticals?

SADLER: No. The supernova rate is far too low to explain even the weakest radio sources in our sample.

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MENON: Your sample of ellipticals is not selected with regard to similarity of environment. Is it not likely that the luminosity function of such a sample does not represent the true luminosity function of isolated galaxies?

SADLER: There are very few truly isolated elliptical galaxies. Most of the galaxies in our sample are in small groups or in the Fornax and Centaurus clusters. We find no obvious environmental effects on radio emission, though the sample contains no very rich clusters and thus may be weighted towards lower-density regions.

KOMBERG: Are there any differences between E-galaxies in the clusters and field E-galaxies?

SADLER: They are not particularly strong, although our sample does not contain galaxies in very rich clusters.