Nuclear activity and the dynamics of elliptical galaxies

M.R. Merrifield

School of Physics & Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD

ABSTRACT

This paper looks for any correlation between the internal dynamics of elliptical galaxies and the relatively mild nuclear activity found in many such systems. We show that there is such a relation in the sense that the active ellipticals tend to be significantly less rotationally supported than their inactive cousins. The correlation can partly be related to the galaxies' luminosities: the brightest galaxies tend to be more active and less rotationally supported. However, even at lower luminosities the active and inactive galaxies seem to have systematically different dynamics. This variation suggests that there are significant large-scale structural differences between active and inactive elliptical galaxies, and hence that the existence of both types of system cannot just be the result of random sporadic nuclear activity.

Key words: galaxies: active – galaxies: elliptical – galaxies: kinematics and dynamics – galaxies: structure

1 INTRODUCTION

Perhaps the most basic remaining question in the study of active galactic nuclei (AGN) is why some nuclei are active while others are not. Now that it is well established that massive black holes lie at the centres of the vast majority of galaxies (Kormendy & Richstone 1995), we know that it cannot be the lack of the necessary power plant, which only really leaves the fuel supply. The simplest explanation then comes down to the duty cycle of the fueling process: in this scenario, all galaxies are active from time to time, and the ones that are observed as AGN are simply the ones that we happen to catch in the act (see, for example, Eracleous, Livio & Binette 1995).

However, there is a problem with this scenario. Bender et al. (1989) showed that elliptical galaxies that are active, as determined by their powerful radio emission, are structurally different from inactive elliptical galaxies. In particular, they showed that radio-loud ellipticals typically have boxy isophotes, while radio-quiet systems have more disk-like distortions in their isophotes. Such boxy isophotes are created in major mergers (Naab, Burkert & Hernquist 1999), which suggests that this violent process might form a suitable triggering mechanism for AGN activity. However, Kauffmann & Haehnelt (2000) showed that such a mechanism would require the subsequent lifetime of the AGN to be only $\sim 10^7$ years to explain the observed frequency of AGN. The secular evolution timescale for an elliptical galaxy to lose its boxy isophotes is very much longer, so one would therefore expect to find a large population of radio-quiet ellipticals that have passed their active phase yet still have boxy isophotes. The absence of such a population in the study by Bender et al. (1989) implies that there must be more to nuclear activity than a simple, universal triggering mechanism.

Indeed, one can come up with a plausible argument as to why nuclear activity might be more generally connected to the large-scale isophote shapes of the host galaxy. Disky isophotes in ellipticals are generally associated with significant rotation, and a galaxy with such strong rotation will contain more material following nearly circular orbits, which avoid the centre of the galaxy. Thus, such systems will not have as ready a fuel supply for the nucleus, explaining the preponderance of active nuclei in systems with boxy isophotes.

Although this connection between galaxy structure and nuclear activity complicates the story somewhat, it is thus far fairly limited in its impact. The powerful radio sources identified in Bender et al. (1989) are almost all hosted by very luminous ($M_B < -21.8$) elliptical galaxies. Since such systems are often the brightest cluster galaxies that lie right at the centres of clusters, they are rather exceptional objects. It should therefore not be particularly surprising if their evolution and the origins of their nuclear activity differed from those of more run-of-the-mill ellipticals. It is hence still possible that generic nuclear activity is not related to the larger-scale properties of the host galaxy, but arises from a simpler, essentially random, fueling process.

In this paper, we set out to see whether this stochastic scenario remains credible, by looking for similar correlations.
between nuclear activity and galaxy structure in fainter elliptical systems with lower levels of AGN activity. Section 2 describes the archival data upon which this analysis is based, and Section 3 presents the results. Section 4 briefly discusses their implications.

2 THE DATA

The most thorough search for weak nuclear activity was undertaken by Ho, Fillipenko & Sargent (1997), who obtained spectra of the nuclei of a magnitude-limited sample of almost 500 galaxies, of which 57 were classified as ellipticals. The emission line strengths of these galaxies were analyzed in Ho, Fillipenko & Sargent (1997), where they were classified as inactive or active, depending on whether nuclear emission lines were detected. The active nuclei were further subdivided into HII nuclei, transition objects, LINERs and Seyfert nuclei, with these classifications in increasing order of excitation. Of the 57 ellipticals under consideration here, 27 were classified as inactive, 5 as transition objects, 21 as LINERs, and 4 as Seyferts. For this study we adopt these classifications as indicators of nuclear activity. We also use the values for B-band absolute magnitude, $M_B$, given in Ho, Fillipenko & Sargent (1997).

If the argument that AGN activity is suppressed by rotational motion is valid for these galaxies, one might expect to find a correlation between the nuclear classifications and the larger-scale dynamical parameters of these galaxies. No homogeneous study has been made of the kinematics of this sample, but the existing long-slit spectral data on a large number of galaxies has been very helpfully collected in the HyperLeda database (Prugniel & Simien 1996), which provides values for the central velocity dispersion, $\sigma$, and maximum rotation velocity, $v$, as derived from all archived long-slit observations along each galaxy’s major axis.

Unfortunately, the data in the HyperLeda archive is of somewhat variable quality, so we have adopted the following protocol to extract “best” estimates for the requisite kinematic parameters. Where there is only one major-axis observation in the database, we use it. Where there are two observations, we use the one with the smaller quoted error. Where there are more than two observations, we take the value with the smallest quoted error: if this number is consistent with the mean and standard error of the remaining observations, we adopt it as the best estimate; if it is inconsistent with the other observations, we reject it and repeat the process. This approach tends to pick out the latest, highest-quality data, rather than averaging good data with bad, but also weeds out the relatively small number of cases where the latest measurement is inconsistent with a consensus of previous observations. Although it is unlikely that this procedure excludes absolutely all bad data, it will not preferentially affect either the active or the inactive systems, so should not prejudice this statistical comparison between the two types. Of the 57 elliptical galaxies in the Ho, Fillipenko & Sargent (1997) sample, the requisite kinematic data are available for all except four, reducing the final sample size to 53 objects.

To assess the significance of the amount of rotation in an elliptical galaxy, we also need to know its observed ellipticity, $\epsilon$. We obtained these values from the 2MASS extended source database, using the published axis ratio measured from the J+H+K super image ("supJ\alpha"), as accessed through the NASA Extragalactic Database (NED).\(^1\)

The final combined data set of galaxy names, nuclear activity classifications, maximum rotation velocities, central velocity dispersions, ellipticities and absolute magnitudes is presented in Table 1.

3 RESULTS

The simplest diagnostic of the dynamics of elliptical galaxies involves a plot of $v/\sigma$ against $\epsilon$. The former quantity provides a measure of the division between streaming and random motions, and on the basis of a simple dynamical argument one would expect galaxies in which this ratio is higher to be more flattened (Binney & Tremaine 1987, p. 216). In fact, most galaxies rotate more slowly than one would predict from their flattening on the basis of the simplest dynamical model (Davies et al. 1983), which is taken as evidence that most ellipticals are not flattened by rotation. Nonetheless, such a plot still forms a very useful diagnostic.

Figure 1 shows the data described in Section 2 presented in this way. As previously mentioned, the vast majority of galaxies rotate more slowly than the prediction of the simple isotropic rotator model. However, it is notable that a few galaxies are “super-rotators,” lying above the curve in

\(^{1}\) The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
At first glance, these galaxies seem problematic, since a rather contrived pure elliptical galaxy dynamical model would be required to populate this part of the plane. However, there is a simple explanation: the observed ellipticity is a truly global measure of the properties of the galaxy, whereas the nature of the spectroscopy means that the kinematic measurements only probe the galaxy close to its major axis. Thus, a relatively modest disk component embedded in an elliptical would have little effect on the measured ellipticity, but could dominate the measured kinematics, making the galaxy appear to rotate faster than its global ellipticity would allow. Alternatively, it is possible that some of these systems are merger remnants that are still evolving, in which case, one would not necessarily expect to find them in the parts of Fig. 1 populated by equilibrium models.

Although these factors complicate the dynamical interpretation of any observed value of \(v/\sigma\), one can still use it to make a comparison between populations: if active and inactive nuclei lie in host galaxies with indistinguishable dynamical properties, then the observed distribution of values of \(v/\sigma\) should be identical for both populations. It is therefore notable that the two distributions do not seem to be the same. In particular, the super-rotators in Fig. 1 are all inactive galaxies. This difference suggests that the moderate AGN in this sample follow a similar trend to the luminous radio galaxies: a large amount of rotation seems to suppress nuclear activity. However, it is not legitimate to pick out regions of this plot \textit{a posteriori} and claim a statistically significant result; rather, one must look at the entire sample without such prejudice, and compare galaxies with differing ellipticities in a consistent objective manner. To this end, one can calculate the quantity \((v/\sigma)^*\) by dividing the observed value of \(v/\sigma\) by the value one would obtain for an isotropic rotator of the same ellipticity [Kormendy 1982]. Thus, galaxies with values of \((v/\sigma)^* \sim 1\) are strongly rotationally supported, while those with \((v/\sigma)^* \sim 0\) rotation is not dynamically significant.

The distribution of this dimensionless rotation parameter for the active and inactive galaxies is shown in Fig. 1. These distributions confirm the qualitative impression of Fig. 1: there is an excess of rapidly-rotating inactive galaxies. A KS test shows that these two distributions are different at \(>95\%\) confidence. There is even some indication of a gradient in the degree of activity with the degree of rotational support: the highest ionization-state “Seyfert” nuclei, highlighted in the lower panel of Fig. 1, seem to lie systematically at even lower values of \((v/\sigma)^*\). However, the size of the sample is too small to establish such a result at a statistically significant level.

One remaining question is whether the active and inactive galaxies differ in some other systematic way that might be the fundamental driver of both their activity and degree of rotational support. In particular, it is well established that brighter ellipticals tend to be less rotationally supported [Davies et al. 1983]. If these brighter galaxies also have systematically higher levels of nuclear activity, then luminosity might be the underlying cause of both phenomena.

Figure 3 shows a plot of \((v/\sigma)^*\) against the absolute magnitudes of the galaxies. This plot confirms the absence of rotational support in the brightest galaxies with \(M_B < -21\). It further suggests that the faintest galaxies also tend to lack rotational support, as first pointed out by Bender & Nieto.

---

Table 1. Final data set.

| Name          | AGN Class | \(v\) (km/s) | \(\sigma\) (km/s) | \(\epsilon\) | \(M_B\) |
|---------------|-----------|--------------|-------------------|-------------|--------|
| NGC 147       | 0         | 6            | 23                | 0.693       | −14.52 |
| NGC 185       | 3         | 3            | 25                | 0.891       | −14.95 |
| NGC 205       | 0         | 3            | 30                | 0.594       | −15.44 |
| NGC 221       | 0         | 45           | 80                | 0.913       | −15.51 |
| NGC 315       | 2         | 32           | 336               | 0.760       | −22.22 |
| NGC 410       | 1         | 40           | 300               | 0.740       | −22.01 |
| NGC 777       | 3         | 35           | 295               | 0.900       | −21.94 |
| NGC 821       | 0         | 84           | 208               | 0.800       | −20.11 |
| NGC 1052      | 2         | 120          | 240               | 0.760       | −19.90 |
| NGC 2634      | 0         | 65           | 190               | 0.920       | −19.96 |
| NGC 5846      | 0         | 60           | 250               | 0.920       | −21.17 |
| NGC 5813      | 2         | 90           | 235               | 0.730       | −22.24 |
| NGC 5638      | 0         | 62           | 154               | 0.920       | −20.11 |
| NGC 5576      | 0         | 10           | 200               | 0.680       | −21.17 |
| NGC 5322      | 2         | 80           | 250               | 0.800       | −22.24 |
| NGC 5077      | 2         | 25           | 254               | 0.780       | −20.83 |
| NGC 4636      | 2         | 27           | 235               | 0.836       | −20.72 |
| NGC 4649      | 0         | 43           | 370               | 0.891       | −21.43 |
| NGC 5707      | 2         | 140          | 210               | 0.600       | −19.06 |
| NGC 5322      | 2         | 25           | 254               | 0.780       | −20.83 |
| NGC 5557      | 0         | 10           | 250               | 0.860       | −21.17 |
| NGC 5576      | 0         | 10           | 200               | 0.680       | −20.34 |
| NGC 5638      | 0         | 62           | 154               | 0.920       | −20.21 |
| NGC 5813      | 2         | 90           | 235               | 0.730       | −20.85 |
| NGC 5831      | 0         | 27           | 152               | 0.920       | −19.96 |
| NGC 5846      | 1         | 60           | 250               | 0.920       | −21.36 |
| NGC 5982      | 2         | 80           | 255               | 0.700       | −20.89 |
| NGC 6702      | 2         | 20           | 172               | 0.760       | −20.95 |
| NGC 7619      | 0         | 63           | 325               | 0.820       | −21.60 |
| NGC 7626      | 2         | 25           | 260               | 0.880       | −21.23 |

\(a\) 0 = inactive, 1 = transition object, 2 = LINER, 3 = Seyfert
Figure 2. Histograms of the degree of rotational support in inactive and active galaxies, as quantified by \((v/\sigma)^*\). The shaded section of the lower histogram indicates the highest ionization state active galaxies, which have been classified as Seyferts.

There is also a clear indication in Fig. 3 that the most luminous galaxies are more likely to be active, with all of the systems with \(M_B < -21.6\) classified as AGN. However, even if one takes the extreme measure of excluding these six galaxies from the sample, the distributions of \((v/\sigma)^*\) for the active and inactive galaxies remain different at > 95% confidence in a KS test. Thus it would appear that, even if one excludes the AGN hosted by the most massive galaxies, there are systematic differences between the dynamics of active and inactive galaxies.

It would be desirable to subdivide the data further in absolute magnitude to look for subtler trends with luminosity. For example, the referee considered the subsample at \(-20.5 > M_B > -21.5\) and pointed out that, if one excludes the two outlying rapid-rotators, there is little to distinguish between active and inactive galaxies. Unfortunately, the data set is really too small to draw any strong statistical conclusions from such subsamples. It is, however, notable that the upper envelope of the fastest rotating galaxies fainter than \(M_B = -21\) seems to consist almost entirely of inactive galaxies. At the very least one can say that, independent of luminosity, there is strong evidence that the most rapidly rotating galaxies are systematically less active than the slower rotators.

4 DISCUSSION

The relationship between nuclear activity and the dynamics of elliptical galaxies, originally established for luminous radio sources in the brightest systems, seems to extend to lower levels of AGN activity in fainter, more ordinary ellipticals. This connection suggests that there is more to AGN activity in ellipticals than a universal stochastic triggering mechanism.

One possibility that we have begun to explore with this data set is that the underlying common factor could be the luminosity (or mass) of the galaxy. Indeed, the most luminous galaxies are all active and tend to rotate slowly. Thus, it is possible that luminosity might be a controlling parameter: more luminous galaxies contain more massive black holes that are more likely to be active, and perhaps the formation mechanism for these very bright systems tends to suppress their rotation. However, even if this is the case, it is not inconsistent with large-scale dynamics playing a critical role in dictating the nuclear activity of a galaxy. If the formation mechanism for elliptical galaxies tends to produce a lower value of \((v/\sigma)^*\) for a more luminous galaxy, then such a luminous system will contain more material on orbits that travel close to the centre of the galaxy. This ready fuel supply will enhance the mass of the central black hole and its current accretion rate, explaining why such a luminous galaxy is so likely to contain an active nucleus.

Quite which mechanisms are the fundamental drivers of AGN activity remains to be established beyond all doubt. However, hopefully this paper has demonstrated that the large-scale dynamics of the galaxy is likely to be a significant factor. In retrospect, this really should not be a surprise: galaxies are fundamentally dynamical entities, and any model of AGN fueling that glosses over this point cannot
provide an accurate description; just because two elliptical galaxies look similar when they are photographed, it does not mean that their inner workings are the same, so there is no reason why both should have the same probability of containing an active nucleus.

ACKNOWLEDGMENTS

I am most grateful to the referee, Philippe Prugniel, for his insights into the importance of luminosity as a parameter when studying nuclear activity and large-scale dynamics.

REFERENCES

Bender, R. & Nieto, J.-L., 1990, A&A, 239, 97
Bender, R., Surma, P., Döbereiner, S., Möllenhoff, C. & Madejsky, R., 1989, A&A, 217, 35
Binney, J. & Tremaine, S., 1987, Galactic Dynamics. Princeton University Press, Princeton
Davies, R.L., Efstathiou, G., Fall, S.M., Ilhingworth, G. & Schechter, P.L., 1983, ApJ, 266, 41
Eracleous, M., Livio, M. & Binette, L., 1995, ApJ, 445, L1
Ho, L.C., Fillipenko, A.V. & Sargent, W.L.W., 1995, ApJS, 98, 477
Ho, L.C., Fillipenko, A.V. & Sargent, W.L.W., 1997, ApJS, 112, 315
Kauffmann, G. & Haehnelt, M., 2000, MNRAS, 311, 576
Kormendy, J., 1982, in Morphology and Dynamics of Galaxies, p.115, eds. Martinet, L., Major, M., Geneva Observatory
Kormendy, J. & Richstone, D., 1995, ARA&A, 33, 581
Prugniel, P. & Simien, F., 1996, A&A, 309, 749, kept up to-date at http://www-obs.univ-lyon1.fr/hypercat/
Prugniel, P. & Simien, F., 2003, Ap&SS, 284, 603
Thorsten, N., Burkert, A. & Hernquist, L., ApJ, 523, L133