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PROFILE OF A KEY PROGRAMME

Towards a Physical Classification of Early-type Galaxies

R. BENDER, Landessternwarte, Heidelberg, F.R. Germany
M. CAPACCIOLI, Osservatorio Astronomico, Padova, Italy
F. MACCHETTO, Space Telescope Science Institute, Baltimore, USA
J.-L. NIETO, Observatoire de Toulouse, France

Hubble was the first who succeeded in classifying galaxies within a scheme of some physical meaning. Although it soon became clear that Hubble's *tuning fork* does not represent an evolutionary sequence, this essential diagram has proven to be a powerful tool especially for the understanding of late-type galaxies. On the other hand, the "early-type" sequence of elliptical (E) and S0 galaxies is less satisfying, because it does not seem to reflect a unique sequence of physical properties. The S0 class, although conceived to bridge the gap between disk- and disk-less galaxies, has often been abused to host ellipticals exhibiting peculiarities incompatible with their definition as structureless objects. For the elliptical galaxies themselves, "ellipticity" has been found to be essentially meaningless with regard to their angular momentum properties, and shows little, if any, correlation with other global parameters. This fact became apparent after the first stellar kinematical measurements of luminous ellipticals (Bertola and Capaccioli 1975, Illingworth 1977): E galaxies are not necessarily flattened by rotation and may have anisotropic velocity dispersions (Binney 1978).

A first step towards a physical classification of early-type galaxies was the investigation of the correlations between the classical global parameters (luminosity, scale length, projected central velocity dispersion, central density, and metallicity/colour). These parameters were found to form a plane in the parameter space ("the fundamental plane"). More specifically, each of these global parameters can be given as a function of two independent parameters, namely in general the central velocity dispersion and the mean surface brightness. The fundamental plane corresponds to the cooling diagram plane of modern theories of galaxy formation, which are based on the self-regulation of the dissipative collapse of protogalaxies (Silk 1983, Blumenthal et al. 1984).

In contrast to the "global" parameters, those describing the detailed shape and kinematics of early-type galaxies (ellipticity gradients, isophotal twists, trends of radial light profiles, velocity anisotropies, etc.) do not correlate with the fundamental plane. This lack of correlations has instilled further suspicion that even the Hubble E class alone is not physically homogeneous (Capaccioli 1987). Indeed, while all ellipticals share roughly the same morphological appearance, they may nonetheless belong to genetically distinct families (see Bender et al. 1988, Nieto 1988, Prugniel et al., 1989). The consequences of this hypothesis are more dramatic than having the E galaxies populate a "2 + N" parameter space (e.g. Djorgovski and Davis 1987, Dressler et al. 1987) since a physical segregation of E types would bear directly on our understanding of the formation/evolution of the different species of galaxies.

An effective tool for separating E galaxies into at least two physically distinct classes has been recently identified with a simple and direct observational parameter which measures the lowest-order axisymmetric deviation (a_4) of the galaxy isophotes from perfect ellipses (Bender 1987). This parameter, easily extracted from good S/N images by Fourier analysis, discriminates between "boxy" ($a_4 < 0$) and "pointed" ($a_4 > 0$) isophotes (e.g. Lauer 1985, Bender and Möllenhoff 1987, and Jedrzejewski 1987).

Bender et al. (1988, 1989) and Nieto (1988) found that these two "shape-classes":
(a) contain ≈80% of all Es, and
(b) isolate objects with distinct physical properties.
More specifically, boxy ellipticals are frequently radio-loud (the power being a function of the mass) and permeated by gaseous "halos" (as inferred from their X-ray emission), while ellipticals with pointed isophotes are usually undetected in the radio and X-ray bands (Fig. 1). There is also a clear segregation of the kinematical properties between these two classes: in most cases boxy ellipticals are flattened by anisotropic velocity dispersion while "pointed" E's are rotationally supported (Bender 1988a, Nieto et al. 1988; see Fig. 2).

The nature of "pointed" E's is easily understood if one assumes (Nieto et al. 1988) that they are internally structured

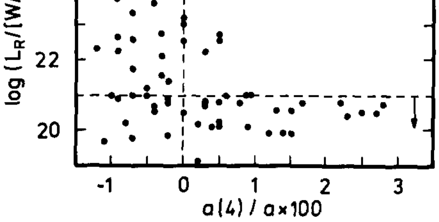

Figure 1: *Logarithm of radio luminosity at 1.4 GHz against isophotal shape parametrized by* a*(4)/*a *(*a*(4)/*a *< 0 indicates boxy isophotes,* a*(4)/*a *> 0 disky isophotes). Below the dashed line most symbols indicate upper limits (Bender et al. 1989).*

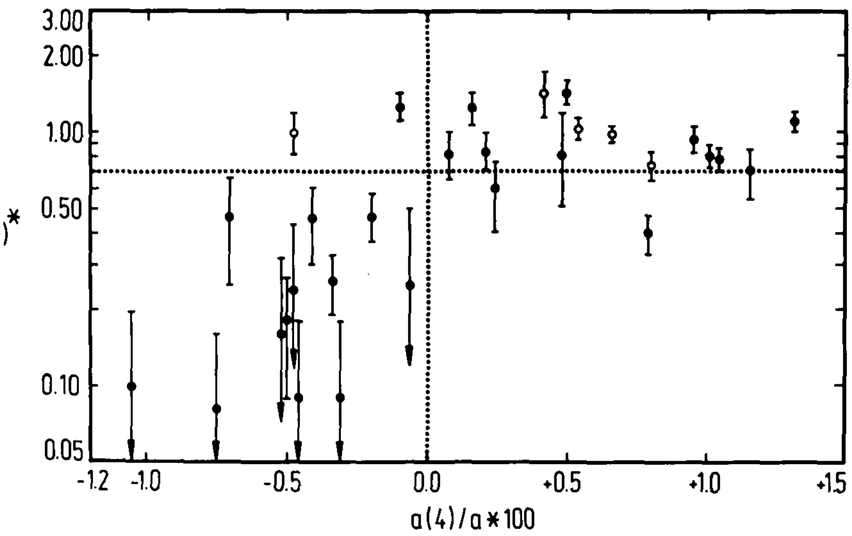

Figure 2: *Anisotropy parameter* $(V_m/\sigma)^*$ *against isophotal shape parameter* a(4)/a. *Boxy ellipticals are in most cases supported by anisotropic velocity dispersions (i.e.* $(V_m/\sigma)^* < 1$*), while nearly all disk-ellipticals are rotationally flattened objects showing* $(V_m/\sigma)^* \approx 1$. *Open circles indicate ellipticals less luminous than* $M_T = -20.5$ *(*H_o *= 50 km/s/Mpc), while filled dots indicate objects above* $M_T = -20.5$ *(Bender 1988a).*

like classical S0's (the pointed isophotes being reasonably interpreted as caused by the superposition of an edge-on stellar disk and an ellipsoidal bulge). Actually, a strong morphological similarity has already been firmly established for those few "disk"-E's where the faint edge-on disk has been disentangled from the bright bulge (Carter 1987, Capaccioli 1987, Capaccioli et al. 1988). Although faint disks harboured in disk-E's obviously have no direct dynamical consequence on host-galaxy evolution, they are nevertheless symptomatic of strong physical differences in intrinsic shape and internal kinematics as compared to boxy E's.

The physical nature of boxy E's is not so clear. Boxy ellipticals are not only anisotropic objects, but also present peculiarities such as, e.g., kinematically misaligned or even counter-rotating cores (Franx and Illingworth 1988, Bender 1988b, Jedrzejewski and Schechter 1988) and other features generally recognized as signatures of *recent* accretion or merging processes (Nieto, 1988). This strongly suggests that boxiness (at least in these objects, see Nieto and Bender, 1989) is related to these violent phenomena. The distinct kinematical differences between boxy and disky E's shed light in particular on the large scatter in velocity anisotropies of luminous ellipticals (the (M_T, $(V_m/\sigma)^*$) diagram, Davies et al. 1983).

What fraction of elliptical galaxies belong to each class? A rough estimate can be obtained from the investigation of a sample of 47 elliptical galaxies of the *Revised Shapley-Ames Catalogue of Bright Galaxies* (Sandage and Tammann 1981) performed by Bender et al. (1988): ~1/4 of bright elliptical galaxies exhibit nearly edge-on stellar disks. From the statistics of inclination angles, one therefore expects that up to 50% of luminous elliptical galaxies could in fact be disk-galaxies with very low D/B ratios ($D/B < 0.05$).

Although the segregation of elliptical galaxies into at least two distinct physical classes seems to be well established now, the cosmological interpretation of this finding is still open. The two classes certainly reflect different historical pasts in terms of interaction with the environment, notably at early stages of galaxy formation.

In particular, it seems that disk-E's, together with S0's and spirals, belong to a continuous sequence in disk-to-bulge ratio ("D/B"), which in turn appears to be related to the *specific* angular momentum (Fig. 3). Therefore, since the frequency of morphological types depends on the density of the environment (Dressler 1980), the discovery of two classes of E's is expected to give new insights in the relation between D/B ratios, the environment and the process of acquiring angular momentum during the primordial collapse phase (see e.g. Barnes and Efstathiou 1987). In addition, comparing the disk properties along the D/B sequence is certainly important in order to understand the mechanisms driving the formation of these flat components; this is not a trivial aspect since disk properties (exponential decline and same central surface brightness μ_o for all objects) are suspected to be independent of the D/B values (van der Kruit 1987, Capaccioli and Vietri 1988).

Unlike disk-E's, whose structure seems to result from initial conditions, boxy E's are probably produced by *recent* violent mergings. However, we

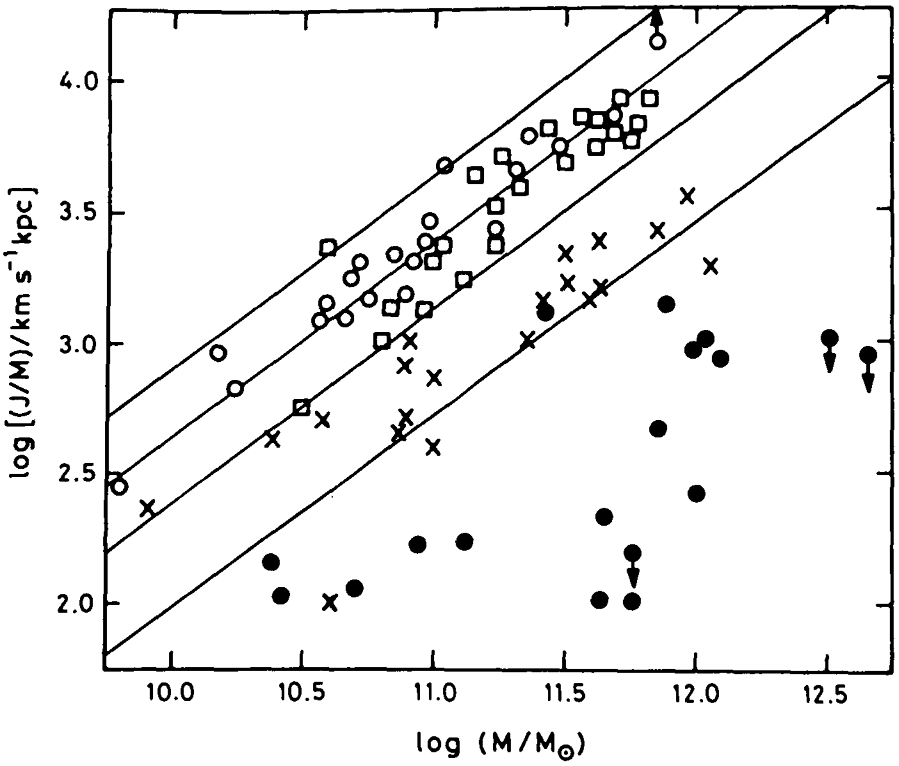

Figure 3: *Specific angular momentum* J/M *(calculated from half-light radius and maximum rotation velocity) against mass in solar units for different types of objects. Sc and Sb galaxies are represented by open circles and squares (adapted from Fall 1983), disk-E's by crosses, and boxy E's by filled circles (Bender et al. 1989, in preparation).*

cannot exclude that boxy E's just represent extreme examples of enivronmental evolution at early phases of galaxy formation. The physical state of the hot interstellar medium, which is present in many of these objects, is certainly of importance for the understanding of formation and present-day evolution of boxy ellipticals.

In summary, the isophotal shape analysis offers a new methodology/tool for a complete revision of the classification of early-type galaxies and our understanding of the underlying formation mechanisms/conditions, provided it is applied to a significant and statistically meaningful sample of objects (in the same way the Hubble classification scheme was applied before). This revision obviously requires a huge research project.

Our key-programme is an attempt to collect all the observational and theoretical expertise to coordinate the efforts toward an effective solution of the problem outlined above. As a first step of the project, we aim to investigate the occurrence of faint stellar disks in E galaxies, their properties, origin, significance, and relation to their analogues in S0's. Surface photometry will be supplemented by kinematical analyses in order to investigate the kinematical behaviour of the spheroids and the distribution of their specific angular momentum. Narrow-band images will be used to study the properties of the interstellar medium and relate the gas properties to the other galaxian parameters (shape of potential, X-ray emission, etc.).

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PROFILE OF A KEY PROGRAMME

Gravitational Lensing

J. SURDEJ[1], J. ARNAUD[2], U. BORGEEST[3], S. DJORGOVSKI[4], F. FLEISCHMANN[5], F. HAMMER[6], D. HUTSEMEKERS[7], R. KAYSER[8], O. LE FEVRE[2], L. NOTTALE[6], P. MAGAIN[1], G. MEYLAN[9], S. REFSDAL[3], M. REMY[7], P. SHAVER[9], A. SMETTE[9], J.P. SWINGS[1], C. VANDERRIEST[6], E. VAN DROM[7], M. VÉRON-CETTY[10], P. VÉRON[10] and G. WEIGELT[5]

[1] Institute of Astrophysics, University of Liege, Belgium; [2] Canada-France-Hawaii Telescope Corporation, Hawaii; [3] Hamburg Observatory, F.R. Germany; [4] Astronomy Department, California Institute of Technology, Pasadena, USA; [5] Physics Institute of the Erlangen-Nürnberg University, F.R. Germany; [6] Meudon Observatory, France; [7] European Southern Observatory, La Silla, Chile; [8] CITA, University of Toronto, Canada; [9] ESO, Garching, F.R. Germany; [10] Haute-Provence Observatory, France

Prior to Professor van der Laan's enquiry, in the March 1988 issue of the *Messenger,* on the general interest among astronomers from the European community to possibly participate in Key Programmes (KPs) at the European Southern Observatory, at least three distinct groups (including more than half of the above authors) were already involved in the study of "gravitational lensing" effects (see box on pages 10–11). Observations were being performed with the help of various telescopes on La Silla as well as at other observatories (VLA, CFHT, Palomar, Kitt Peak, etc.).

A general feeling existed that our individual work was progressing very slowly, the number of effective nights that were allocated to our programmes being modest, also very much dependent on unknown weather and/or seeing conditions, on possible instrument failures as well as on the sometimes unpredictable decisions of the programme committees. We all knew that there was a total absence of coordination between our independent programmes and that, of course, we could not avoid duplicating observations of similar objects. Fur-