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THE VIRGO CLUSTER - HOME OF M87

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ABSTRACT. Our current understanding of the structure and dynamics of the Virgo cluster is reviewed. Special emphasis is given to a possible connection between the activity of M87 and the cluster as a whole. The Virgo cluster is an aggregate of at least three separate subclusters, centered on M87, M86, and M49. The dominant M87 subclump, with a mass of a few 10^{14} $M_{\odot}$, is outweighing the other two subclumps by an order of magnitude. There is evidence, from the kinematics of dwarf galaxies and the structure of the X-ray gas, that the M86 subclump is falling into the M87 subclump from the back with a relative velocity of $\approx$ 1500 km s^{-1}. M87 and M86 seem to be embedded in a common, cocoon-like swarm of dwarf ellipticals. The orientation of this cocoon, or simply the line connecting M87 and M86, is coinciding with the (projected) direction of the jet of M87. A possible explanation for this apparent coherence between structures on the pc scale of the center of M87 and the Mpc scale of the Virgo cluster is discussed.

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1. INTRODUCTION

The purpose of this review is to provide the astrophysicist who specializes in AGN, and in M87 in particular, with some astronomical background on the physical environment of M87, which is of course the well-known Virgo cluster of galaxies. I try to convince the reader that such knowledge is not only of cosmographical interest but may be essential for an understanding of certain features of the central engine of M87. For some, still unknown reason there is a remarkable coherence between the orientation of the jet axis of M87, which is probably defined by the spin axis of the central black hole on a pc scale, and the orientation of the Virgo cluster on a Mpc scale.

For an astrologer, this micro-macro connection would come as no surprise. Consider the figure of Virgo from Hevel's beautiful *Uranographia* (1690), reproduced here in Fig. 1. The position of M87, which can be identified with respect to the stars, happens to coincide with the ellbow joint of Virgo's left arm, which is hidden behind her left wing. It has always been a mystery what Virgo is pointing at with her left hand. Now we know: this is the direction of the jet of M87, to within 30 degrees.
So much for astrology in *this* contribution to the present volume.

Figure 1. The figure of Virgo from Hevel's *Uranographia* (1690). North is up, West to the right, as in a modern representation. Everything appears mirrored because the entire sky map was drawn on a globe, to be viewed from the outside. The cross is indicating the position of M87 and the arrow is the direction of its jet.

A mere hundred years after Hevel we find the first mention of the *phenomenon* of the Virgo cluster, still way before its extragalactic nature was known, by Charles Messier in *Connaissance des Temps pour 1784* (see Tammann 1985 for the original passage). Messier noticed an unusual concentration of nebulae in the constellation of Virgo. Fifteen out of the 109 ``Messier'' objects are, in fact, Virgo cluster members. By identifying them on a conventional sky atlas, one can notice that the Messier's alone nicely trace out the direction of the jet of M87!

From the rich 20th-century history of the Virgo cluster I mention only the landmark studies of Harlow Shapley and Adelaide Ames in the 30-ties (Shapley, who, ironically, in the ``Great Debate'' of 1920 had been the opponent of Heber Curtis, discoverer of the jet of M87) and Gérard de Vaucouleurs and collaborators in the 60-ties and 70-ties (for more history see Tammann 1985).

The modern view of the Virgo cluster presented in the following is essentially based on the Las Campanas photographic survey of the Virgo cluster by Allan Sandage and collaborators (involving the writer), the galaxy redhifts measured by John Huchra, Lyle Hoffman and many others, and the ROSAT imaging of Virgo by Hans Böhringer and colleagues.

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2. GLOBAL STRUCTURE

Fig. 2 is a map of the ca. 1300 galaxies in the area of the Las Campanas survey of the Virgo cluster (Binggeli et al. 1985) judged to be cluster members. The membership criteria were based on (1), the morphological appearance of the galaxies; e.g. dwarf ellipticals, which constitute the dominant population of the cluster, have a characteristically low surface brightness; and/or (2), the measured radial velocities. The velocity criterion works of course only if the cluster is sufficiently isolated in space. Fortunately, this seems to be the case, i.e. there is a small void behind the cluster (although not quite so in the case of spirals and irregulars which form a sort of filament that runs through the cluster, cf. Sect. 4 below). Velocities are available only for the brightest 400 members. However, morphology is an equally efficient tool to pick up the members; later velocity measurements have nearly always confirmed our morphological judgement (e.g. Drinkwater et al. 1996). Detailed galaxy morphology is of course limited to the most nearby clusters, such as Virgo.

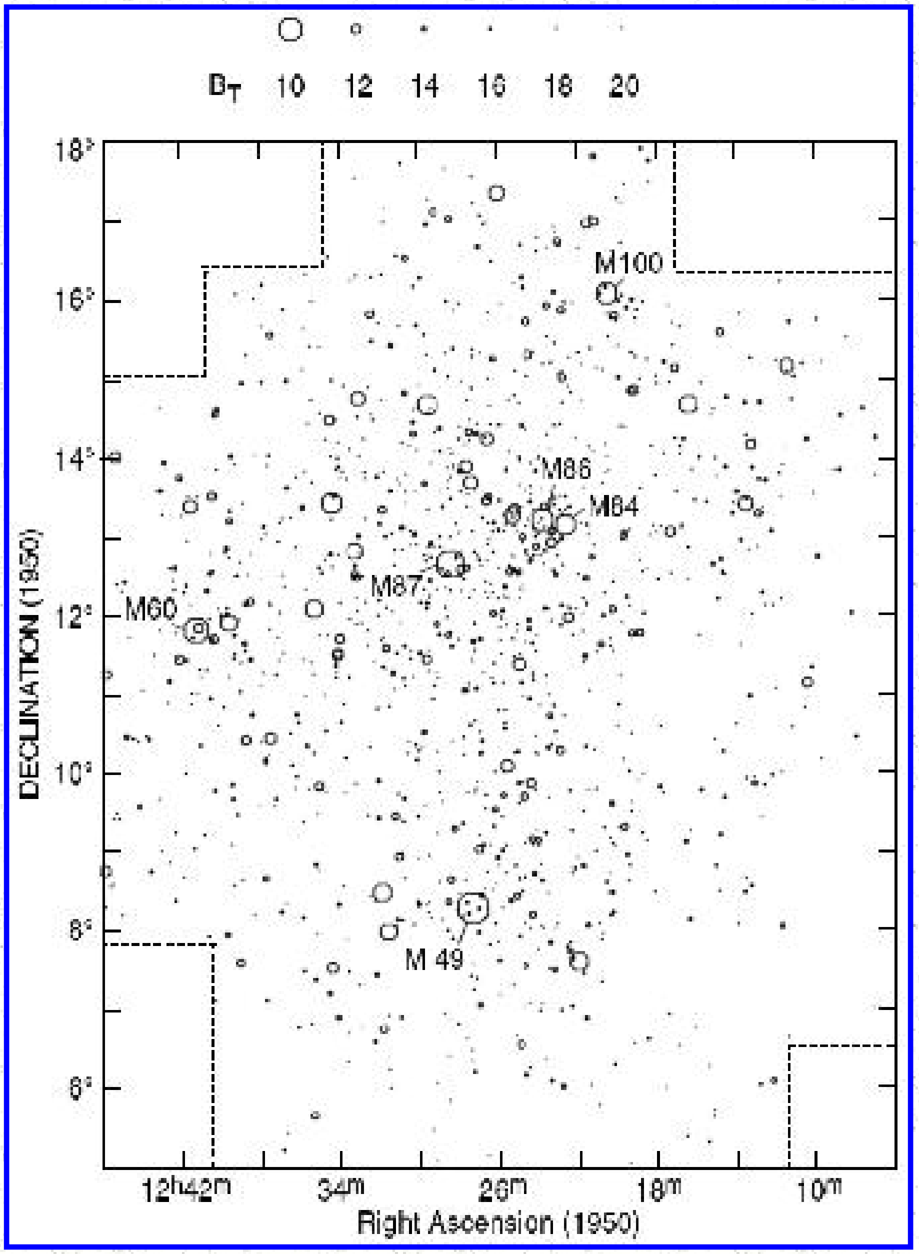

Figure 2. Map of the Virgo cluster. All cluster members are plotted with luminosity-weighted symbols. The symbol size (area) is proportional to the luminosity of the galaxy. The apparent magnitude scale is given on top of the figure (absolute magnitudes follow from $m - M = 31.5$ if a distance of 20 Mpc is adopted). The most prominent Messier galaxies are indicated. Figure from Binggeli et al. (1987).

The magnitude limit of completeness of the Las Campanas survey is around $B_T^{lim} = 18$, or, if we assume a distance of 20 Mpc, $M_{B_T}^{lim} = -13.5$. Undoubtedly, there are hundreds, if not thousands of more, extremely faint members of the Virgo cluster - analogous to the dwarf spheroidal companions of our Galaxy (Phillipps et al. 1998). However, these will unlikely alter the structural appearance of the cluster.

Let us now have a look at the structure of the Virgo cluster based on Fig. 2. The primary characteristic is certainly the overall irregularity of the cluster. Although we would not hesitate to call M87 the ``king" of the Virgo cluster (despite the fact that it is not even first-ranked in apparent magnitude; M49 is slightly brighter), it is not *the* center of *the* cluster. But it is the center of the most massive subcluster, as we shall see below. If one naively draws density contours (isopleths) with a suitable smoothing (number or luminosity-weighted), as in Binggeli et al. (1987), M87 is off the peak density (the cluster ``center") by almost one degree. That peak density is closer to the M84 / M86 lump, to the NW of M87. However, our smoothing was rather like putting a mattress on the bumpy back of a camel. There is clear evidence for a secondary subcluster around M86 (see below), so we deal with a double structure, a double conglomerate of galaxies in the central part of the Virgo cluster. The two subclusters, called here the ``M87 subclump" and the ``M86 subclump", seem to be in a state of merging. Although this becomes clear only when we discuss the kinematics and the X-ray properties of the cluster below, the central double structure is quite obvious already from a simple plot of the galaxy postions in the sky (Fig. 2).

There is another double structure of the Virgo cluster on a larger scale, along N-S, defined by the northern M86 / M87 subclump structure (called ``cluster A" in Binggeli et al. 1987) on the one hand, and the southern galaxy concentration around M49, called here the ``M49 subclump" (= ``cluster B") on the other hand. Possibly, there is a small subclump around M60 (= ``cluster C"). A number of very small bound subsystems, essentially groups of galaxies consisting of one bright galaxy plus a swarm of dwarf galaxies (as, e.g., M100 + satellites in the far North), are likely to exist, but these are difficult to identify even with kinematic data (for the general question of bound companions in the Virgo cluster, see Ferguson 1992, and Binggeli 1993).

So there are two main axes of the Virgo cluster: one N-S, i.e. M100-M86 / M87-M49, and one E-NW, i.e. M60-M87-M84 / M86. Remarkably, the former axis is nearly perfectly aligned with the position angle of the outer isophotes of M87 (e.g., Weil et al. 1997), while the latter is perfectly aligned with the jet axis of M87. The two axes appear also very prominently in the X-ray image of the Virgo cluster (Fig. 5).

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3. GALAXY CONTENTS AND KINEMATICS

The distribution and clustering properties of galaxies in clusters are known to depend strongly on the Hubble type (Dressler 1980). The Virgo cluster is no exception of this. Fig. 3 shows the projected distribution of Virgo cluster members devided into the main morphological types: giant early types (E + S0), dwarf early types (dE + dS0), spirals and smooth, magellanic-type irregulars (S + Im), and clumpy irregulars (blue compact dwarfs, BCD). Only galaxies with known velocities are depicted, although this is a restriction only for the dEs, as all other types are essentially complete with respect to kinematic data (all dEs are shown in Fig. 9, Sect. 6, in a different context).

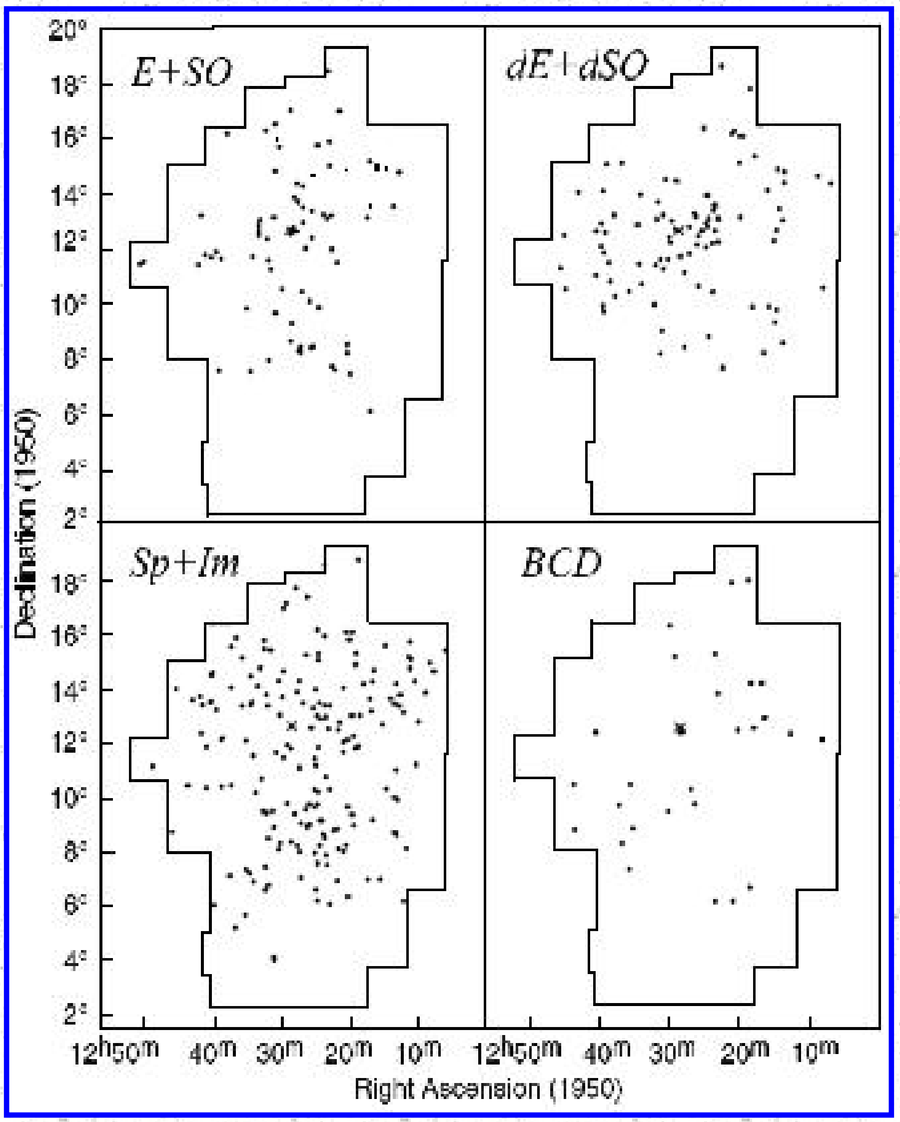

Figure 3. The distribution of the main morphological classes of galaxies in the Virgo cluster: E + S0, dE + dS0, spirals + magellanic irregulars, and clumpy irregulars (BCDs), shown in four panels. Only galaxies with known radial velocities are shown. The irregular-shaped contour is indicating the area of the Las Campanas Survey of the Virgo cluster (Binggeli et al. 1985). The crosses mark the position of M87. Figure from Binggeli et al. (1993).

From Fig. 3 we note: (1) late-type galaxies are much more dispersed than early types - independent of luminosity, (2) The southern M49 subclump is very spiral and irregular-rich, unlike the northern M87 / M86 subclump structure, (3) the E-NW axis of the cluster, which is aligned with the projected jet direction of M87, is nicely traced out by the Es and S0s, (4) there is a prominent asymmetry in the distribution of dEs with respect to M87 (of which more in Sect. 6 below). For more details, including the Dresslerian morphology-density relation for the Virgo cluster, the reader is referred to Binggeli et al. (1987).

These morphological differences are even more pronounced in the kinematic space. In Binggeli et al. (1993) we have collected and statistically analysed the radial velocities of ca. 400 Virgo cluster members. Most measurements are from the optical *Center of Astrophysics Redshift Survey* (Huchra et al. 1983, Geller & Huchra 1989) and the *Arecibo* H I survey of late-type Virgo members by Hoffman et al. (1987, 1989). Special efforts to get the velocities of a number of dE galaxies, which play a key role in our analysis, are due to Bothun & Mould (1988). In fact, all 800 odd Virgo members still lacking a velocity are dEs: their notoriously low surface brightness renders spectroscopy essentially unfeasible, at least at present.

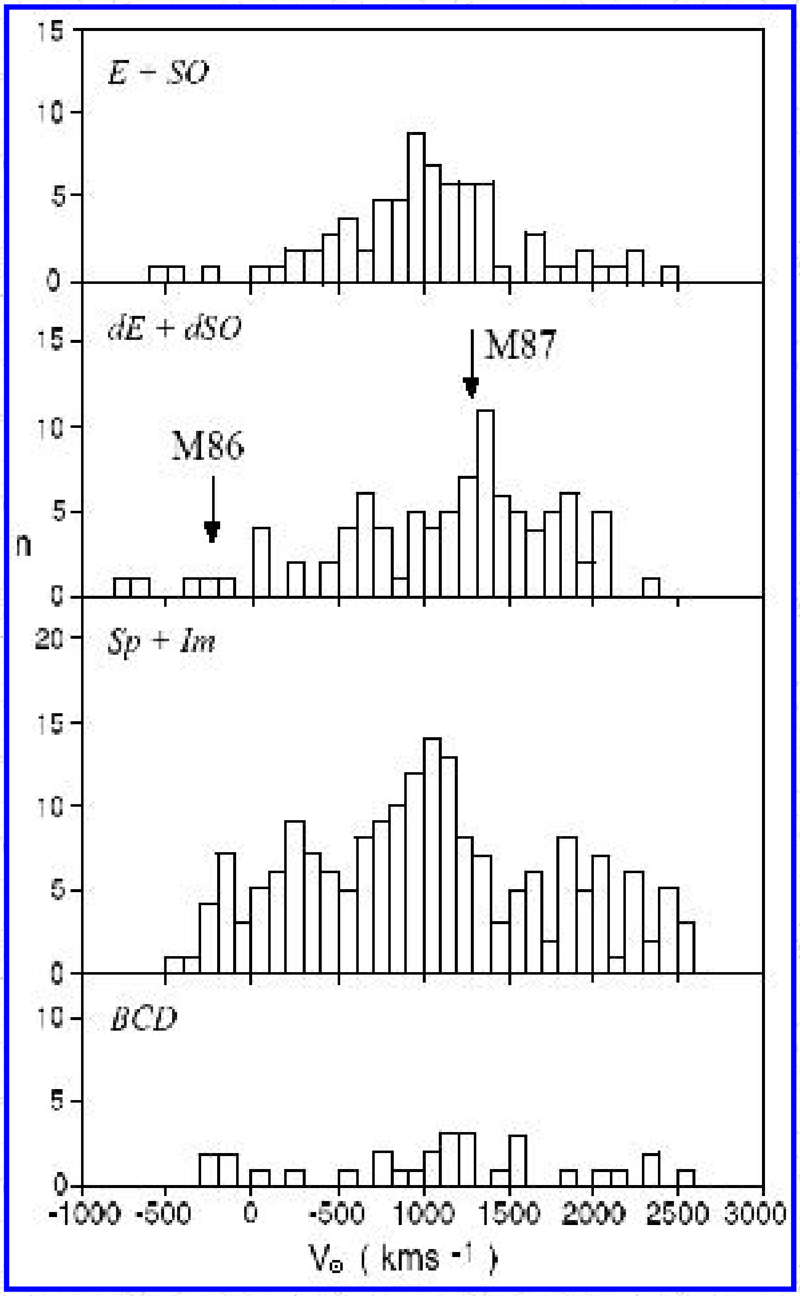

Figure 4. The heliocentric velocity distributions of Virgo cluster members divided into the four main morphological classes shown in Fig. 3. The velocities of M86 and M87 are indicated in the panel for early-type dwarf galaxies.

The basic kinematic data for the main morphological types, reproduced from Binggeli et al. (1993), are listed as velocity means and (r.m.s. or 1σ) dispersions in Table 1, and shown as distributions in Fig. 4. From these we note the following: (1) the velocity distribution of late-type members (spirals and irregulars) is significantly broader than that of early types (giant and dwarf E + S0s), i.e. late types are more dispersed in space *and* velocity, (2) the velocity distribution of spirals and irregulars is distinctly non-Gaussian, though it is fairly symmetric with a low-velocity and a high-velocity wing, (3) the velocity distribution of dwarf ellipticals is non-Gaussian *and* non-symmetric, being skewed towards low velocities, (4) the velocity of M87 is off the cluster mean by +200 km s^{-1} (as its projected position is also off a naively determined global cluster center), but is coinciding with the peak (median) of the velocity distribution of dEs, (5) the velocity of M49 is not significantly different form the cluster mean, while the velocity of M86 is even negative, coinciding with the low-velocity tail of the velocity distribution of dEs.

Table 1. Heliocentric velocities of Virgo clustermembers

sample	*N*	< *v* > (km s^{-1})	σ_v (km s^{-1})
E + S0	75	1017	589
dE + dS0	93	1139	649
S + Im	188	1031	737
BCD	29	1110	795
All	399	**1064**	**699**
M87		*1258*	
M86		*-227*	
M49		*969*	

These kinematic features, in connection with the projected spatial distributions discussed before, have been interpreted in the following way (cf. Huchra 1985, Binggeli et al. 1987, 1993). The broad velocity distribution of spirals and irregulars likely means that most of these galaxies are not yet relaxed (virialized); if they are only bound to the cluster, one indeed expects a velocity dispersion that is higher by $\approx \sqrt{2}$ than the dispersion of the presumably older, relaxed E + S0 population. The existence of low and high-velocity wings in the S + Irr distribution is a strong indication for infalling/expanding shells of late-type galaxies around the core of the cluster. It is quite plausible that nearly all spirals and irregulars are late, or even future arrivals, and hence are not yet virialized. The surrounding low-density field of the cluster, where these types of galaxies predominate, is subject to a global clustercentric velocity perturbation with a characteristic infall pattern (Rivolo & Yahil 1983, Tully & Shaya 1984). Field late-type galaxies are constantly fed into the cluster. Based on H I properties, it seems even possible to discriminate beteween spirals that have already fallen through the cluster core and spirals that are still in approach: the former, which are typically found in the central cluster area, are naturally identified with those spirals that are strongly H I-deficient (Haynes & Gionavelli 1986) and have very small H I disks (Cayette et al. 1990).

A clear asymmetry in the velocity distribution of a cluster of galaxies is almost certainly an indication of ongoing subcluster merging (e.g. Schindler & Böhringer 1993). The present asymmetric velocity distribution of Virgo dEs is taken as sign of the merging between the M87 and M86 subclumps (or rather, the infall of the M86 subclump into the more massive M87 subclump), for which there is additional evidence from X-ray observations, as will be discussed in Sect. 6. Both giant galaxies are obviously the centers of huge swarms of dwarf ellipticals, which is why the velocity of M87 is coinciding with the peak of the dE velocity distribution and not with the cluster mean, while M86 is apparently falling into, or through the M87 subclump from the back, hence with a high relative (negative) velocity, dragging along a smaller swarm of dwarfs, some of which are the most blueshifted galaxies in the sky (cf. Sect. 6). Finally, the well-behaved velocity of M49, coinciding more or less with the cluster mean, would suggest that the M49 subclump is approximately at the same distance as the M87 / M86 core structure, and that their supposed future merging will take place in the plane of the sky. This view is supported by the lack of a significant difference in the distance moduli of the M49 and M87 / 86 subclumps based on a host of different distance indicators (cf. Federspiel et al. 1998).

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4. CLUSTER DEPTH AND ENVIRONMENT

The absolute distance of the Virgo cluster is still a matter of debate. Distances quoted range from 15 to 22 Mpc. In general, the most reliable extragalactic distance indicators are of course the Cepheids. Cepheids at (and slightly beyond) the Virgo cluster distance are now within the reach of *HST*. This achievement was so long awaited that the first Cepheid-based distance determination of a Virgo cluster spiral (M100) by Freedman et al. (1994) had an enormous impact. The resulting distance of ca. 17 Mpc was simply taken as *the* distance of the Virgo cluster. But we know (cf. above) that Virgo spirals avoid the cluster core and may be in the field far off the cluster. M100 is probably lying at the near side of the cluster. Indeed, as more spiral distances are nailed down by *HST*-observed Cepheids, the average distance of the spirals is growing (Tammann and Federspiel 1997). Recently, Böhringer et al. (1997) have made the clever suggestion to use spirals as *HST*-Cepheid targets that show clear signs of ram pressure stripping, thereby ensuring proximity to the cluster core.

The safest would be to use only elliptical and S0 cluster members (or, ideally, M87 alone!) for a distance determination. Unfortunately, the primary RR Lyrae stars are much too faint at the distance of Virgo even for *HST*. The secondary distance indicators which can be applied to Virgo ellipticals give controversial results: globular clusters, $D_n - \sigma$, and novae tend to give large distances ($D \simeq 20$ Mpc), surface brightness fluctuations (SBF) and planetary nebulae (PN) lead to a small $D \simeq 16$ Mpc (an overview of the methods can be found in Jacoby et al. 1992). Great efforts are spent in the application of the SBF method (Tonry et al. 1997) because its claimed distance uncertainty for an individual galaxy is almost as small as with Cepheids ($\lesssim$ 0.2 mag). However, Tammann (e.g. Tammann 1996, Tammann & Federspiel 1997) argues that the method is not yet mature for use, as long as the variations of the stellar populations among ellipticals are not really understood. A different problem might also undermine the PN method (Tammann 1996).

Fortunately, the absolute distance of the Virgo cluster is not very relevant for our discussion, and for definitiveness I continue to use $D = 20$ Mpc. More interesting is the question of the depth of the cluster. Can we resolve this depth with any of the distance indicators in use? What accuracy in the distance modulus would be required? According to Fig. 2, the angular width of the Virgo cluster in the sky is $\simeq 8°$. Assuming the cluster is as deep as it appears wide (i.e. approximate spherical symmetry), and with a mean distance of 20 Mpc, the front-to-back depth is 2.8 Mpc, or $\lesssim$ 0.3 mag in distance modulus. So the cluster could just barely be resolved with the most accurate distance indicators.

But again: this assumes spherical symmetry. Should the cluster be deeper than wide, in the form of a cigar or finger pointing towards us, we might resolve (or claim to resolve) the cluster depth with even the worst distance indicator. This happened in the early days of the SBF method (Tonry et al. 1988) when the cluster literaly exploded. Since then, people have become more cautious, and an apparent dispersion of the SBF distances among Virgo ellipticals beyond of what can be expected from spherical symmetry is usually ascribed to unaccounted-for variations in the stellar populations (Pahre & Mould 1994, Jensen et al. 1996). A recent claim by Young & Currie (1995) that *dwarf* ellipticals are distributed in a prolate structure pointing towards us, based on the shape of the luminosity profile of these galaxies, has been shown to be flawed (Binggeli & Jerjen 1998). There is presently no indication that early-type galaxies in the Virgo cluster are *not* as strongly clustered in space as they are observed to be in sky projection.

Remains the Tully-Fisher method for spiral galaxies (and of course also the Cepheids, which, however, are too costly for a gross application) to map the outskirts and the large-scale environment of the Virgo cluster. There is consistent evidence that Virgo spirals are distributed in a prolate cloud, or filament, stretching essentially from the cluster backwards to the so-called ``W cloud'' - again roughly along our line of sight (Fukugita et al. 1993, Yasuda et al. 1997, Federspiel et al. 1998). There is no doubt about the reality of the feature: spiral and irregular galaxies in the Local Supercluster are known to be gathered in filamentary ``clouds'' of galaxies (cf. Tully & Fisher 1987). The Virgo spiral filament is probably part of a very long filament that runs from Virgo way back to the ``Great Wall'' at the distance of the Coma cluster (Hoffman et al. 1995), and it might even be connected, on the near side, with the ``Coma-Sculptor cloud'' that runs through, i.e. includes the Local Group (cf. Tully & Fisher 1987). If so, we should not be surprised to observe a ``finger of God'' - because we *live* in a finger of God.

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5. THE M87 SUBCLUMP

The absolute dominance, in terms of mass, of the M87 subclump in the Virgo cluster is not well seen in the optical (Fig. 2, which shows the luminosity distribution of the cluster), but it becomes strikingly clear from an X-ray image of the cluster. The reason for this is that, on the assumption of hydrostatic equilibrium, the hot X-ray gas is directly tracing the gravitational potential, i.e. the dark mass of the system in which it is embedded. In Fig. 5 we reproduce a *ROSAT All-Sky-Survey* image of the Virgo cluster, which is identical in scale to the optical image in Fig. 2. As mentioned by Böhringer et al. (1994), who did the definitive study of the X-ray properties of the Virgo cluster, there is good overall match between the optical and the X-ray, even in detail, note e.g. the relatively sharp Western edge seen in the optical as well as in the X-ray. This means that the galaxies and the hot gas are more or less in equilibrium. However, there is this striking difference in appearance of the M87 / M86 core structure. In the optical, we note a swarm of galaxies around M86 / M84, which of course is responsible for shifting the optical center of the cluster away from M87 (see Fig. 2), while in the X-ray, M87 is clearly *the* center of the cluster, or more precisely: it is clearly lying at the bottom of the most massive subclump. This is evidence that at least the core of the Virgo cluster is not in dynamical equilibrium. Our interpretation of what is going on in the core has been mentioned before: there is a smaller subclump around M86 which is falling into the dominating M87 subclump from the back (Binggeli et al. 1993, Böhringer et al. 1994). From the X-ray halos of M87, M86, and M49, Böhringer et al. (1994) estimate several times 10^{14} $M_{\odot}$ for the mass of the M87 subclump, and an order of magnitude less for the mass of each of the M86 and M49 subclumps.

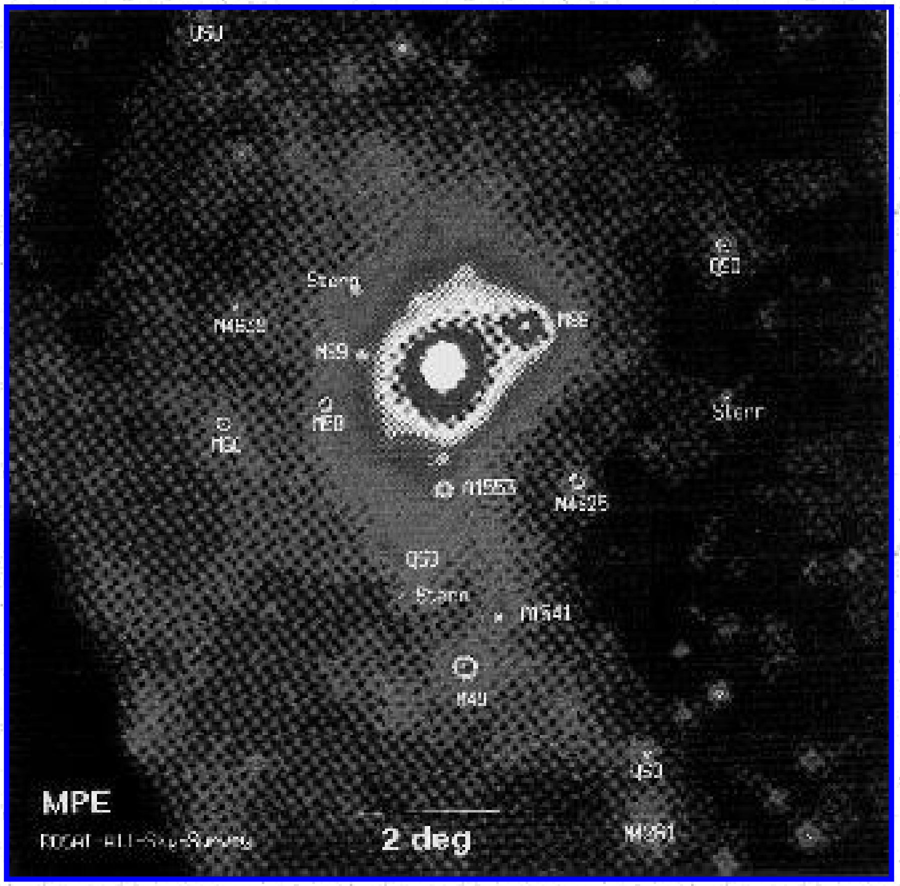

Figure 5. X-ray image of The Virgo cluster from the *ROSAT All-Sky-Survey*. Various foreground stars, quasars, Abell clusters, and Virgo cluster members (NGCs and Messiers) are indicated. The large, bright spot is centered on M87. The scale is identical to that of Fig. 2. Note the bright halos of M49, M86, and - very massive and dominating - M87. Courtesy of Dr. H. Böhringer and the *MPE*, Garching.

The M87 / M86 subclump interaction will be further discussed below. Here we concentrate on the M87 subclump. Nulsen & Böhringer (1995) have used *ROSAT* data to calculate the mass profile of the M87 subclump (superceding, but more or less agreeing with, the classic study by Fabricant & Gorenstein 1983, based on *Einstein* data). Two components could be distinguished in the mass profile, one belonging to the galaxy M87 itself, which is in good accord with the masses indicated by the stars and the globular clusters of M87 (refs. given in Nulsen & Böhringer 1995), and one belonging to the subclump in which M87 is embedded. However, the mass (dark matter) profile is really continuous, and it would seem to be difficult to discriminate between ``M87 subclump'' galaxies that are gravitationally bound to M87 proper and others that are merely bound by the subclump as a whole. Nevertheless, this is what I have tried to do several years ago (Binggeli 1993), and I show some of this here because it gives me the opportunity to show the closer galaxy environment of M87.

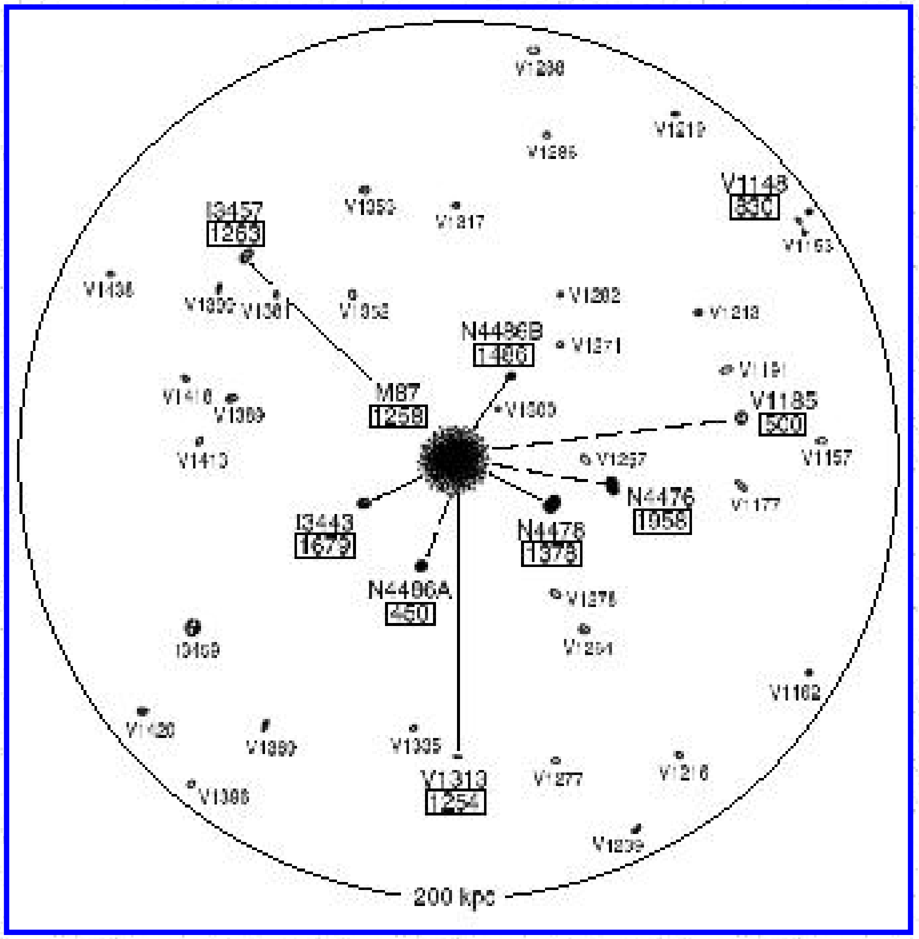

Figure 6. Detailed map of the neighbourhood of M87 within a projected radius of 200 kpc. The size and morphology of the galaxies is schematically indicated (filled image = high surface brightness, open = low surface brightness, central dot = nucleus, irregular contour = irregular). Faint galaxies are identified by their VCC number (Binggeli et al. 1985). Possible satellites are connected to the center by lines. Figure from Binggeli (1993).

Fig. 6 is a schematic of this environment, within a projected radius of 200 kpc from M87. There are 41 Virgo cluster members in this area, only 10 of which have known velocities (including M87). Most of these must be bound to the M87 subclump; some might also belong to the M86 subclump. But what we can try to do is to find those galaxies which are likely bound companions to the *galaxy* M87, in the following way. For a candidate companion we require, in addition to the (pre-selected) small projected distance, d, a sufficiently small velocity difference, $| v |$, to M87. These two quantities can now be combined to give a ``projected mass'', $q = | v |^2 \cdot d / G$. By averaging $q$ for $N$ candidates, and multiplying the result with a suitable constant $f$ that accounts for the distribution and projection of orbits, one gets a ``projected mass'' estimate for the central object (Bahcall & Tremaine 1981). Since we know the mass profile of M87 from the X-ray halo, we can now add up possible companions with growing q until the upper-limit X-ray mass from Nulsen & Böhringer (1995) is exceeded, i.e. until the mass of M87, at that average projected distance, needed to bind the would-be companions becomes too large. With $f = 24 / \pi$ (cf. Bahcall & Tremaine 1981), I found five candidates in this way, which in combination give a total ``projected mass" for M87 at $d \lesssim$ 85 kpc of $\lesssim 4 \cdot 10^{12}\ M_{\odot}$, which is (made to be) in accord with the X-ray mass of M87 at that radius. These five candidates are listed with their relevant data in Table 2. Note also the smallness of their relative luminosities, which is a working condition for the method of Bahcall & Tremaine (1981). All five galaxies are, in fact, fairly compact in their appearance (see Fig. 6); NGC 4486B, e.g., is legendary as a M32-type compact elliptical; so they are very probably companions to M87 indeed. However, two other *apparently* good candidates, NGC 4486A and NGC 4476, are certainly not real companions: the ``projected mass" of each of these galaxies alone far exceeds the X-ray mass limit. Many more of the remaining 30 dwarf galaxies with unknown galaxies might be M87 satellites, of course.

Table 2. Possible satellites of M87

galaxy	type	L/L_{M87}	$\lvert \delta v \rvert$ (km s^{-1})	d (kpc)	q ($10^{12}\ M_{\odot}$)
VCC 1313	BCD	0.001	4	130	<< 0.01
IC 3457	dE3,N	0.013	5	139	<< 0.01
NGC 4478	E2	0.094	120	55	0.18
NGC 4486B	E1	0.013	228	46	0.55
IC 3443	dE0,N_{pec}	0.003	421	47	1.93

d = projected distance to M87

q = ``projected mass" (see text)

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6. THE M87 / M86 SUBCLUMP INTERACTION ...AND THE JET

We now enter the most interesting and perhaps most important issue of the Virgo cluster structure: the interaction between the M87 and M86 subclumps. The *galaxy* M86 has long been known to interact with the intracluster medium (ICM) of the Virgo cluster: Forman et al. (1979) discovered a plume in the X-ray structure of M86, which they inetrpreted as being due to ram pressure stripping of the hot gas of M86 by the Virgo ICM. This general picture has recently been confirmed by Rangarajan et al. (1995) based on *ROSAT* data, although these authors find no evidence for a cooling flow associated with an apparent optical emission seen on very deep photographs (Nulsen & Carter 1987). The surprisingly high metal abundance in the X-ray plume is attributed to the destruction of dust in the stripped material. From the morphology of the X-ray structure of M86, Rangarajan et al. (1995) estimate a southward velocity of M86 in the plane of the sky of ca. 500 km s^{-1}, in addition to the radial velocity, relative to M87, of almost -1500 km s^{-1} (cf. Table 1).

However, we probably do not deal with a single galaxy, M86, that is plunging through the Virgo ICM at a high relative speed and thereby suffering ram pressure stripping. The large gas fraction of M86 is more typical for a whole group of galaxies (Böhringer et al. 1994). A first hint at the existence of a such a group, or rather the ``M86 subclump" of galaxies, was found in the velocity distribution of dwarf ellipticals (Binggeli et al. 1993). So we have a small X-ray cluster, the M86 subclump, which is banging into a big X-ray cluster, the M87 subclump (note that this is more specific than the ``Virgo ICM"), from the back.

Let us have a closer look at the velocities of dwarf ellipticals just mentioned. The velocity distribution of dEs was shown in Fig. 4, and attention was drawn to the fact that this distribution is asymmetric, with M87 coinciding with the peak at higher-than-average velocities, and with a long tail of low velocities around the velocity of M86. This asymmetry was taken as evidence for the ongoing merging of the M87 and M86 subclumps.

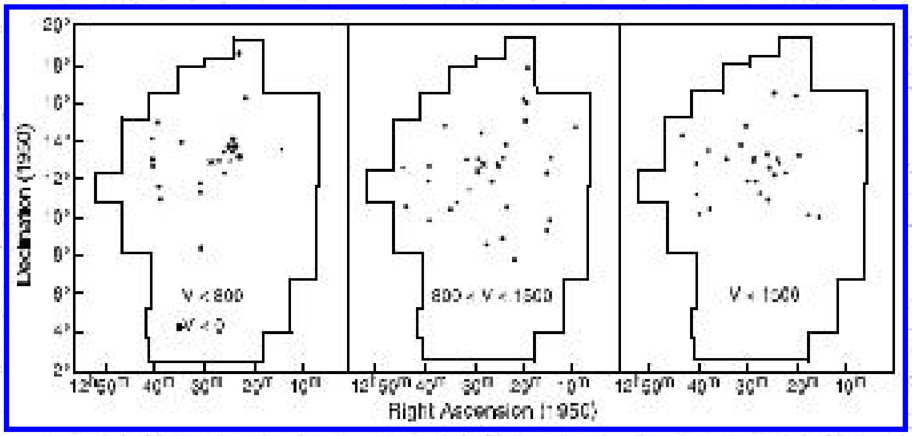

Figure 7. The distribution of dwarf ellipticals in the Virgo cluster shown for three different velocity ranges: low velocities (v < 800) in the left panel, velocities close to the cluster mean (800 < v < 1500) in the central panel, and high velocities (v > 1500) in the right panel. Velocities are heliocentric and in km s^{-1}. The irregular contour is the boundary of the Las Campanas Virgo cluster survey (Binggeli et al. 1985). The position of M87 is indicated by a cross. Note the concentration of high-velocity and low-velocity dEs to the right of M87. In particular, there is a clustering of dEs with negative velocities around M86 (drawn as fat dots). Figure taken from Binggeli et al. (1993).

That the strange distribution of dE velocities is indeed coupled with M87 and M86 becomes more obvious by plotting the projected positions of the dwarfs in the cluster for different velocity ranges. This is shown in Fig. 7. Two features are striking: (1) there is a strong clustering of low-velocity dEs, in particular *negative*-velocity dEs, to the NW of M87, around M86, (2) there is a concentration of high-velocity dEs to the W of M87. The dEs with negative velocities are interesting in themselves, because two of them are, in fact, the most *blue*-shifted galaxies known in the sky! Although there is good reason to hunt for the most *red*-shifted galaxies in the universe, it is only just that these blue-record holders are finally portrayed - which I do in Fig. 8.

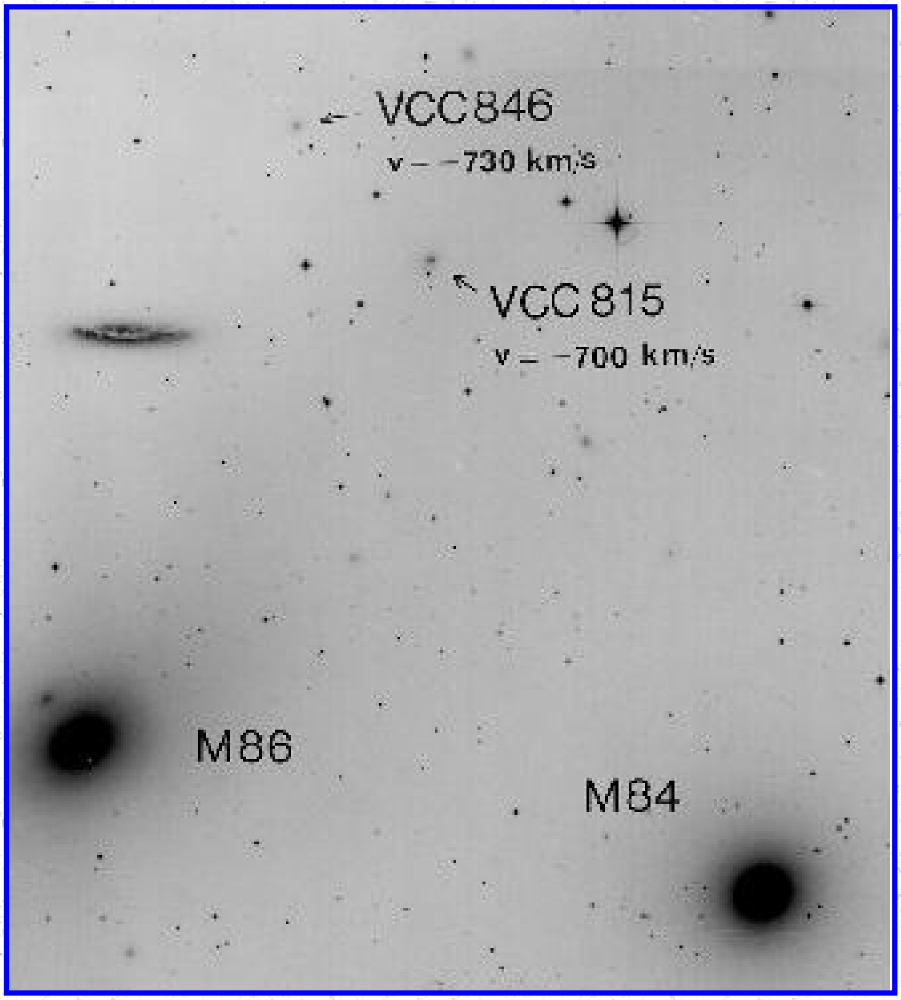

Figure 8. A small piece of the Virgo cluster reproduced from one of the 67 Las Campanas photographic plates used for the Virgo cluster survey (Binggeli et al. 1985), showing M84, M86, NGC 4402, and a number of inconspicuous dwarf galaxies, two of which, however, are the most blue-shifted galaxies in the whole sky known to date: VCC 815 and VCC 846 with heliocentric velocities of -700 and -730 km s^{-1}, respectively. The scale of the photograph is given by the angular distance between M84 and M86, which is 18 arcminutes.

How can we interpret the concentration of dwarfs to the W of M87? The dEs with the most negative velocities ($v \lesssim -700$ km s^{-1}) are ca. 500 km s^{-1} off M86, which we suppose is at rest with respect to the M86 subclump as a whole. Thus, these dEs could simply constitute the low-velocity tail of the M86 subclump, even with a velocity dispersion that is significantly smaller than 500 km s^{-1}. On the other hand, one could envision a rather small intrinsic (original) velocity dispersion of the M86 subclump, in which case the negative-velocity dwarfs would have been accelerated by the tidal influence of the M87 subclump. Conversely, the concentration of high-velocity dEs to the W of M87 could be due to M87 subclump members that have been tidally accelerated towards M86.

At this point we have, finally, to look at the distribution of *all* 800 odd dEs in the cluster, not only those for which we have a velocity. This is presented in Fig. 9. We note a very striking clump of dEs in the central region defined by M87 and M86, which is best seen with the very faintest dEs ($B_T > 18$, in the right panel). The feature looks somewhat like a cocoon that is embedding M87 and M86 at its extreme ends. Without modelling, i.e. numerical simulation of the Virgo cluster dynamics with a full account of galaxy morphology, it remains unclear what this dE cocoon, including its kinematic oddities discussed above, exactly means. However, its very existence strongly suggests that these dwarf galaxies are not in equilibrium with the rest of the cluster. We take it as best evidence for the strong ongoing interaction between the M87 and M86 subclumps.

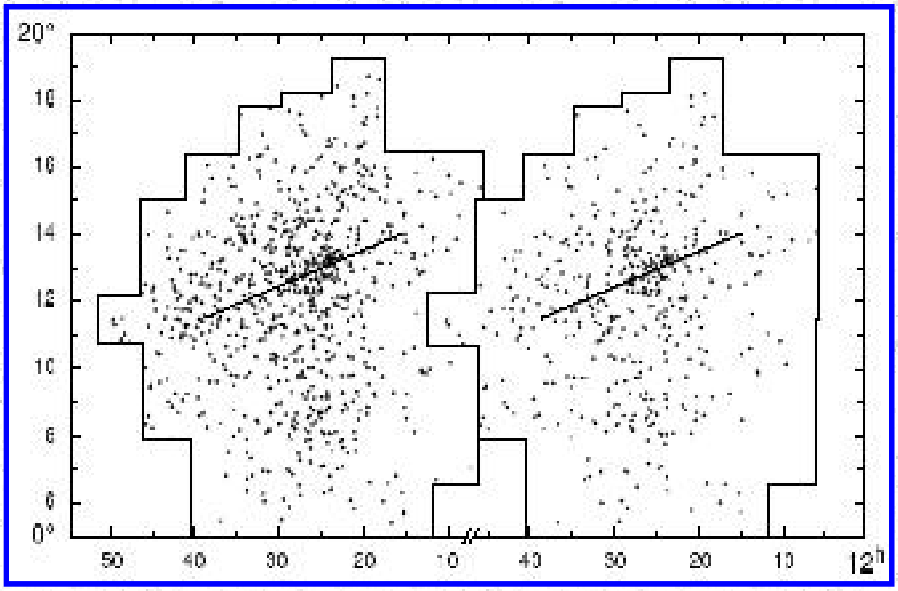

Figure 9. The distribution of all 828 dwarf ellipticals (left panel) and of the 476 dwarf ellipticals fainter than $B_T = 18$ (right panel) in the Virgo cluster. The positions of M87 and M86 are indicated by filled circles. The jet axis of M87 is shown as line. The irregular contour marks the boundary of the Las Campanas survey of the Virgo cluster (Binggeli et al. 1985). Note the dense, elliptical-shaped concentration of dEs which fills the area between M87 to M86 along the jet axis of M87.

But perhaps the most remarkable feature of all is the perfect alignment of the symmetry axis of this interaction, i.e. the elongation of the dE cocoon, or simply the direction from M87 to M86, with the (projected) jet axis of M87. The merging of the two subclumps is taking place on a Mpc scale, while the jet is likely originating from the central pc of M87 - this is a factor of one million difference in scale! To put it bluntly: - *how does the jet know of the position of M86?*

Recently, a very interesting model has been put forward by West (1994) which might explain the observed coherence of structures from the AGN scale to the large-scale structure of the universe. The top-down chain of events evoked by West (1994) goes roughly as follows. During the early epoch of cluster formation, a central dominant (often a cD) galaxy is built via mergers of smaller galaxies. These mergers proceed in a coherent manner along preferred directions which are related to the large-scale cluster surroundings. As a consequence of this anisotropic formation process, the central galaxy is prolate in shape and has a built-in memory of the shape of its parent cluster. Cold gas falling into the prolate potential well will settle into a disk whose angular momentum vector is aligned with the major axis of the central galaxy. Angular momentum loss results in an inward flow of gas, leading to the creation and feeding of a black hole whose spin axis will be aligned with the angular momentum vector. Radio jets are expected to emanate along the black hole spin axis, and thus will be aligned with the major axis of the central dominant cluster galaxy.

This model explains two observed alignment effects: (1) the shape of the central cluster galaxy tends to be aligned with the surrounding distribution of matter on a scale of ca. 20 Mpc, (2) the radio major axis of strong radio galaxies, defined by the radio lobes, tends to be aligned with the optical major axis. The first effect was found for relatively low redhifts, but it will probably also hold for high-redshift clusters. The second effect is only for high-redshift radio galaxies. At lower redshifts, i.e. later epochs, the radio-optical alignment might be washed out by the relaxation of the stellar component, though West (1994) does give low-redshift examples with a strong alignment, such as *Cygnus A*. In combination, the two alignment effects lead to a coherence of structures from parsecs to Megaparsecs.

Could the model of West (1994) explain the alignment of the jet axis of M87 with the M87-M86 axis? First, we should note that the major axis of the galaxy M87 is not pointing in this direction, but is rather oriented NNW, ca. 50° off the jet axis (e.g., Weil et al. 1997). However, as we have seen in Sect. 2, the position angle of the galaxy M87 is in accord with a second cluster axis, viz. that defined by the line connecting M87 and M49. In fact, it is in perfect accord with ``Supergalactic Equator'' (cf. Fig. 4 in Binggeli et al. 1987), which is the symmetry axis of the Local Supercluster. Hence the shape of the galaxy M87 is, after all, aligned with its surroundings on a 20 Mpc scale.

But the jet is pointing to M86, or rather: the projection of the jet is. In 3D space, the jet is pointing towards us at an angle of 30° - 40° to the line of sight (Bicknell & Begelman 1996, also Bicknell in this volume). So - is it just a coincidence? Without taking resort to an extremist scenario, such as Arp's (1986, also Arp in this volume), I find this hard to believe. Not only M86 and M84 are lying ``in the way''; there are also M59 and M60 on the other side, and there is a whole chain of ellipticals tracing out the projected jet axis (cf. again Figs. 2 and 3 here, and Figs. 4 and 7 in Binggeli et al. 1987). This is suggesting *some* kind of causal connection between the orientation of the jet and the distribution of matter on a Mpc scale, be it along the lines of West's (1994) model, or by some yet unknown processes.

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7. CONCLUDING REMARKS

The Virgo cluster is a typical cluster in every sense, and we would not expect it to be otherwise. Not even the fact that it is made of (at least) three smaller clusters (one of which is grossly dominating in mass, however), which are on the verge to merge, turns out to be very special. Many other clusters, at a closer look, show almost exactly the same features. A good example is the somewhat more distant Centaurus cluster, where we distinguish between a massive, X-ray emitting and dE-rich subclump (centered on the cD NGC 4696) and at least one less massive, spiral-rich unit, which is falling into the dominant structure with a high relative velocity (Jerjen 1995, Stein et al. 1997). Even the Coma cluster, formerly the prototype of a hypthetical class of ``regular'', ``relaxed'' clusters, has given way to this picture: it also is an aggregate of three subunits, two of which must have merged long ago, but still show traces (as the respective central dominant galaxies, NGC 4874 and NGC 4489, are not yet merged), and the third of which (centered on NGC 4839, of Virgo cluster size and mass!) is in the process of merging (White et al. 1993, Colless & Dunn 1996). We seem to live in the epoch of rich cluster formation.

What *is* special about the Virgo cluster, for us, is of course its proximity. There is no other cluster of comparative richness lying that close (Fornax, Ursa Major, and Coma I are all much less rich than Virgo). That the cluster is harbouring an active galaxy is not unusual (in fact, as Blandford emphasizes in this volume, M87 is a fairly lousy, i.e. inactive AGN). But again: it is the proximity which may render M87 a kind of Rosetta stone for AGN astrophysics. Indeed, enormous efforts are spent in the attempt to unveil the secrets of the center of M87, of which this volume bears ample witness. The efforts spent to investigate the extragalactic *environment* of M87 are very small in comparison. However, as I tried to show here, the central pc of M87 may be intimately connected with the structure and dynamics of the Virgo cluster as a whole.

Of the many features of the Virgo cluster yet to be studied, I mention two which I regard as especially relevant for the present discussion. (1) As mentioned before, we still lack radial velocity data for ca. 800 Virgo members. Among them are the hundreds of dEs which form the cocoon around M87 / M86. It would be highly desirable to know the velocities of as many of these dwarfs as possible, to get a more complete picture of the cluster kinematics. Present-day technology should allow the measurement of at least the brighter of these objects. (2) Based on such data, with the projected positions of all, and the radial velocities of nearly all Virgo galaxies, plus (possibly) the X-ray gas distribution taken as model input (initial conditions), one could ``run'' the whole Virgo cluster. In particular, one should be able to simulate the M87 / M86 subclump interaction, or at least put useful constraints on its dynamics. For a full 3D simulation, the computing time might be prohibitively large. However, even with very simplifying assumptions to save computing time, such a simulation might be very rewarding. A cluster simulation with realistic, i.e. observed quantities as input parameters (not only in the statistical sense, but galaxy-by-galaxy) has not yet been carried out. The Virgo cluster would be the obvious first choice for such a project (for a first, crude attempt, see Schindler & Binggeli 1994).

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