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KINEMATICS OF SPIRAL GALAXIES; AN OVERVIEW

Paris Pişmiş

Instituto de Astronomía
Universidad Nacional Autónoma de México

RESUMEN: Se presenta una reseña de la cinemática de galaxias espirales con especial énfasis en las curvas de rotación. Sus máximas extendidas y sus ondulaciones en galaxias de tipos tardíos. Los campos de velocidades bi-dimensionales de la línea 21-cm de HI, así como las de óptica, sostienen el argumento de que los máximos y mínimos de las ondulaciones corresponden bastante bien a los brazos e interbrazos. Se argumenta que todas las galaxias muestran actividad en sus núcleos de más o menos intensidad. La energética de la actividad muestra un rango muy amplio: desde los más activos cuasares hasta galaxias "normales". Como ejemplo de una actividad leve se señala a NGC 4736. Tales casos caen en una clase a la cual yo llamaré MAGN, distinguiéndola de AGN (M implica "mildly"). Finalmente sugiero que la secuencia morfológica de las galaxias es esencialmente definida por dos parámetros globales independientes con los que la galaxia se origina. Uno de los parámetros y sin duda el más importante, es la masa total. Un segundo parámetro, sin especificar por ahora, puede ser la energía cinética total. El resto de los parámetros serán deducibles de los dos independientes. Este autor cree que las características principales, tanto morfológica como dinámica, son esencialmente determinadas por las condiciones iniciales aunque las consecuencias de interacción entre galaxias no pueden despreciarse en algunos casos.

ABSTRACT: The kinematics of spiral galaxies are reviewed with special emphasis on rotation curves, the flat maxima and undulations of these curves in late types spirals. The two dimensional velocity fields from the HI 21-cm line as well as from optical lines support the finding that the maxima and minima of the rotation correspond reasonably well to arm and interarm regions respectively. It is argued that all galaxies show nuclear activity of some sort. The energetics of the activity cover a very wide range; from the most active QSO's down to "normal" galaxies. NGC 4736 is given as an example having mild nuclear activity at its nucleus which gives rise to a tight nuclear spiral. Such cases fall into a class which I call MAGN as against AGN (M stands for mildly). Finally, it is suggested that the morphological sequence of galaxies is essentially fixed by the global parameters with which a galaxy gets started. It appears that two independent initial parameters underlie the morphological sequence of galaxies. One such parameter is the total mass which doubtless is the most important one. The second parameter, unspecified as yet may be, the total kinetic energy or any other parameter. The remaining parameters will be derivable from the two independent ones. This writer believes that the main features both morphological and dynamical are essentially determined by global initial conditions although consequences of interaction between galaxies in some cases cannot be ruled out.

Key words: GALAXIES-SPIRAL — GALAXIES-KINEMATICS — HUBBLE SEQUENCE — NUCLEI-AGN-MAGN

I. INTRODUCTION

Kinematic information on spirals is of great significance as it helps to shed light, together with morphological information, on the dynamics of galaxies, and this knowledge, in turn, helps to pave the way towards understanding the dynamical evolution of galactic masses.

The study of kinematics of galaxies, to date is entirely based on information gathered from Doppler shifts of spectral lines which may be of emission or absorption, and in all accessible regions of spectrum, optical, radio or otherwise. The first proof that a galaxy rotated was given by Slipher in 1914, and by Wolf in Germany at about that date. These were heroic times. Slipher secured the spectrum of the central region of M104 with an exposure of 35 hours! The spectral lines were definitely inclined, which Slipher interpreted correctly as a manifestation of the rotation of the galaxy. Shortly after Pease at Mt. Wilson obtained spectra which extended the velocity data to the regions outside the nucleus of M104 with an exposure of 79 hours. Thus, there remained no doubt that spiral galaxies rotated.

Not much work was done in this direction until the late 30's when Mayall, Babcock and Aller worked on the kinematics of nearby galaxies. Babcock's determination of the complete rotation curve of M31 extended to 100 arcmin (Babcock 1939). Velocity data from the radio region of the spectrum did not come in until the late 50's; van de Hulst *et al.* (1957) were the first to give a velocity intensity map of an external galaxy, M31, using the HI 21-cm line. This study extended the velocity data of M31 to a radius of 2°.5, 1° farther than Babcock's determination, however with much less resolution. In the last twenty years or so detailed velocity fields with the 21-cm line were obtained on other nearby spiral galaxies. On the other hand, integrated velocity profiles of the HI line have been determined for a large number of spiral galaxies. These yield V_{max} only.

A systematic attack towards obtaining rotation curves from spectroscopic radial velocities was made by Burbidge and collaborators between 1959 and 1965. (A complete listing of about 30 spirals is given by Burbidge and Burbidge 1975). Meanwhile, Walker (1968) with better resolution and more detail, investigated a few spirals, using the 120" coudé spectrograph with a Lallemand image tube and at the prime focus spectrograph. The dispersions were 68 A mm^{-1} at the coudé and 95 A mm^{-1} at the prime focus, as against 330 A per mm of most of Burbidge *et al.* spectra. At present 25 A per mm is common practice.

II. TECHNIQUES TO OBTAIN RADIAL VELOCITIES

A spectrograph is the most commonly used instrument for radial velocity work; howeve échelle spectrographs are coming into use extensively. Photographic detection is being replaced by photon counting techniques. Fabry-Pérot interferometry with a fixed or variable spacing yield overall velocity fields of emission regions. Here again photographic plates are being replaced by photon counting detectors. Radio telescopes have been used in the HI 21-cm line and lately also in molecular lines to give two dimensional velocity fields of galaxies. Scanning Fabry-Pérot interferometry is similar to the radio astronomical technique in that both yield velocity-intensity maps of spectral lines; aside from the average velocity of a point they both can give in a more direct fashion the dispersion of velocities around the average. Radial velocities of the CO molecular lines have also been obtained in a number of galaxies. To my knowledge, velocities from radio recombination lines are not yet available for want of higher sensitivity.

III. THE ENIGMATIC HUBBLE SEQUENCE OF GALAXIES

It is well nigh impossible to discuss galaxian problems without recalling the classification scheme advanced by Hubble, already some sixty years ago. The great majoriy of observe galaxies fall into one or another of the types. After the sequence of elliptical, "amorphous" galaxies, the sequence is divided into two branches: the so called normal (S) spirals and the barred ones (SB), SO being at the division point. The spiral arms open up from Sa to Sb and Sc or from SBa to SBb and SBc. This sequence set up by Hubble has prompted evolutionary interpretations although Hubble made it quite clear that his scheme was only a working convenience. Anothe criterion for the Hubble classification is the relative importance of the nuclear bulge with respect to the outer parts, the importance of the former decreasing from Sa to Scd. To date we d not know what phenomena cause galaxies to have different large scale morphologies. It is my conviction, evidently shared by many, that the evolution of the large scale features of a galaxy is fixed essentially by its initial parameters and not necessarily by its age.

The initial parameters referred to are essentially the following: the total mass, the specific angular momentum, density distribution (mass concentration),luminosity and color distributions, magnetic fields and others of more local importance. These parameters are not independent of one another. It appears that at least two independent parameters are needed to explain the Hubble sequence. All other parameters except the total mass are subject to change during the evolution of a galaxy. This implies that the mass determined at present is the initial mass. The importance of mass estimates of galaxies cannot therefore be overestimated. After all, gravitational forces arising from the mass are the overwhelming ones in the dynamics of assemblies of galactic size. We shall comment later in this review on some relevant statistical correlations between the different parameters mentioned above.

a) *Internal Kinematics; Rotation Curves.*

In spiral galaxies and even in irregulars rotation is the dominant motion. Going from the center of a spiral outwards there is a more or less steep rise to a maximum velocity, V_{max} at R_{max} followed by a slow decline. Such was the accepted typical rotation curve of a spiral until a decade ago. At present we have ample data to safely state that rotation curves exhibit extended maxima and that in very few galaxies do the curves show an appreciable decline (Rubin 1983).

Attention was directed back in 1965 to the fact that rotation curves of about 75% of spirals by Burbidge, Burbidge and Prendergast and by Walker and collaborators showed irregularities in the form of waves; it was suggested that these "waves" were physically significant features and not observational artefacts (Pişmiş 1965, 1975). I had argued that the phenomenon met a natural explanation in terms of different kinematic components, or stellar populations, in our and other galaxies; in other words, the maxima correspond to arm and the minima to inter-arm regions. Indeed, rotation curves obtained with higher precision and extending farther out from the center verified the existence of "undulations" (Rubin *et al.* 1980) as they were termed later. An alternative explanation for the waves is provided by the density wave theory according to which there are streaming motions along the spiral arms (see for example Wielen 1974).

Rotation curves of Sa and Sb galaxies do not show significant undulations while in Sc galaxies they are commonly observed (see Figure 2, in Rubin 1983). It will be interesting to explore central regions with higher dispersion, in search of waves in the nuclei of galaxies. Perhaps within the fast rising branch there are undulations which are smoothed out at low resolution.

Optical rotation curves mentioned above usually represent data obtained along the apparent major axis (nodal line) or reduced to it. Radio-telescopes give, however, an intensity-velocity map and hence a complete 2-dimensional display of radial velocities. Undulations are clearly present in all directions within well observed spirals in the 21-cm line. It appears therefore that undulations are rather the rule than the exception. In this connection we refer the reader to Bosma's (1978) montage of the isovelocity contours of 32 field galaxies. In Figure 1 we reproduce the observed HI isovelocity contours of M83 (Rogstad *et al.* 1974). The wiggles in the isovelocity curves are the undulations discussed above. It might be interesting to derive from such a map the rotation curves in several directions (position angles) to find out if the wiggles are indeed displaced gradually as a function of radius if they indeed are related to spiral arms. It should also be useful to check further the location of the undulations with respect to spiral structure.

b) *Symmetries, Asymmetries and Warps from two Dimensional Velocity Maps.*

Isovelocity contours depicted in Figure 1 show clearly that rotation of a disk cannot reproduce the observed contours since in case of pure rotation isovelocities would show symmetry around the projected rotation axis as well as around the direction perpendicular to it. The contours show clearly that in the majority of cases no such symmetry is observed (see montage in Bosma's thesis. There exists however a large scale symmetry of another kind, namely a bi-symmetry in the sense that the isovelocity contours would coincide if the image were rotated by 180 degrees around the center. This circumstance indicates that the position angle of the kinematic major axis, which is the line joining the different radial velocity maxima, does not remain constant; instead it varies gradually from the center outwards. This tendency is sometimes accompanied by the change of direction of the morphological "major axis". Which is, then, the nodal line of the galaxy? This phenomenon of the change of position angle of the nodal line is termed a warp of the symmetry plane -the disk- of a galaxy.

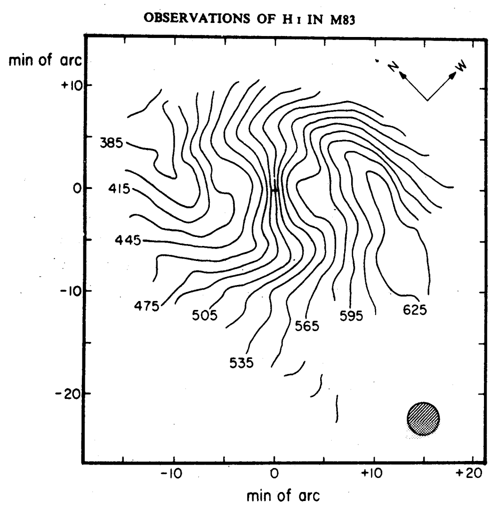


Fig. 1. Mean velocity field of HI en M83 expressed in contour intervals (Rogstad *et al.* 1974).

Bending of the outer regions of the spiral image is well known in edge-on galaxies. NGC 4762 is the most outstanding specimen where one extremity curls upwards and other, downwards (see Hubble Atlas for an image of this galaxy). The deviation of the optically estimated major axis in an inclined, and not edge-on, spiral at times was take as a sign of a warp. This is not always true. A deviation of the "major axis" will be produced if a spiral *is not logarithmic* and there is no theoretical reason known so far why spiral arms should be logarithmic. I have shown earlier (Pişmiş 1967) that if spiral structure is coplanar, and if the equation of the spiral deviates from a logarithmic one, the major axes will show gradual change of position angle going from the center outwards.

In a recent paper, Sandage and Humphreys (1980) attribute this optical change of major axis direction of M33 to a "severe" warp of the plane. 21-cm kinematic warps are observed much farther from the center, usually beyond the Holmberg radius so that the warp suggested by Sandage and Humphreys has no kinematic counterpart and hence is probably caused by the non-logarithmic shape of the spiral arms. A warning: one should accept as unquestionabl a morphological warp only when it is observed at an edge-on galaxy. This fact supports my conclusions that the gradual deviations of the "major axis" along a radius are not sure signs of a warp, particularly when it is not accompanied by a kinematic warp.

It is interesting to point out that in at least two galaxies, NGC 5055 and NGC 7331, going from the center outwards, the position angle of the kinematic major axis wobbles.

To explain the warps an *ad hoc* model was put forward by Rogstad *et al.* (1974) according to which a warped galactic disk is composed of rings tilted gradually from the center on. Simulations using this model have reproduced quite well the isovelocity map of M83 given in Figure 2 (compare this with the observed velocity field of Figure 1). However, a ring model is difficult to justify physically. Incidentally, it is more reasonable to expect that spiral arms may not be co-planar, although this again needs a physical justification.

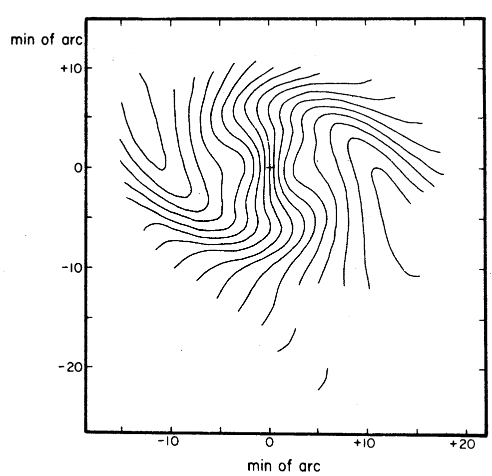


Fig. 2. Isovelocity contours for M83 computed with the tilted ring-models.

Two kinds of patterns in the isovelocity contours are distinguished. In both cases the kinematic major axis changes its position angle as a function of radius vector. In the inner parts of a galaxy a misalignment of the kinematic major and minor axes is believed to be related to optical structures; the observed kinematic minor axis in this case is not perpendicular to the major axis. It is usually suspected that the presence of an oval distortion (a fat bar) causes this misalignment. Further out, beyond the optically visible image of the galaxy HI continues, and the change of its kinematic major axis is suspected to be the signature of a warp, hence the term kinematic warp. In many cases the orthogonality or not of the major and minor axes may not be discerned unambiguously.

Oval distortions (or tri-axial configurations) show up on deep photographs of spirals thoug there exist many structural details within the "ova istortion". Central oval formations are obtained during the evolution of n-body simulations. erhaps this result gives support to the postulated fat-bar models. The velocity field generated n the presence of a central potential of the kind is found to be consistent with the tendency o deviation of the major axes in the central regions. For the outer deviations, a tilted ring odel is so far the generally accepted mechanism to produce the warp. It is my personal view hat two different mechanisms, one for the inner and another for the outer regions, to explain he phenomenon of the smoothly varying position angle of the major axes, is rather artificial. ne expects the processes in nature to be more or less continuous.

Optically obtained 2-dimensional velocity fields are coming up: these also exhibit i-symmetry. It is worth mentioning that the bi-symmetry of the velocity field can be explained f along with rotation there were radial motions as well. This is not a favored explanation since arge radial motions (inward or outward) do not seem to be detected in the outer parts of galaxies. I shall argue later that in the nucleus itself radial motions are indeed operative.

) *Nuclear Regions of Spiral Galaxies*: AGN.

I shall specify a nuclear region as a sphere with radius of about 1 kpc. Complexities n the kinematics had been detected in the sixties, in the nuclei of galaxies which were not eyferts by definition (Walker 1968). At present, with data of high spatial and spectral resolution they constitute a topic of intensive study. The kinematic complexities consist of deviations rom the expected circular motion -"non-circular" motions either outward or inward. A list of alaxies showing radial motions in their nuclei is given in Table 1.

TABLE 1. Radial Motions in Nuclear Regions

Galaxy	Type	Radial Motions	References
M31	Sb	Outward	Rubin and Ford (1970)
NGC 253	Sc	Outward	Gottesman *et al.* (1976), Ulrich 1978
NGC 1068	Sb (Seyfert)	Outward	Walker (1968)
NGC 4151	Sa (Seyfert)	Outward	Walker (1968), Ulrich (1973)
NGC 4736	Sb	Outward	van der Kruit (1976)
NGC 2903	Sc	Inward	Simkin (1975)
NGC 3351	SBb	Inward	Rubin *et al.* (1975*b*)
NGC 3672	Sc	Inward	Rubin *et al.* (1977)
NGC 5383	SBb	Inward	Duval (1977)
NGC 6764	SBs3 (Seyfert)	Inward	Rubin *et al.* (1975*a*)

The most energetic ones are discussed under the heading Active Galactic Nuclei (AGN). ncluded in this group are the quasi-stellar objects (quasars), BL LAC objects, blue compact obects, radio galaxies, etc. down to Seyferts 1 and 2. AGN's constitute a very fashionable topic t present. However, in my view all galaxies show activity in their nuclei involving the liberaion of energy in more or less degree, thermal and/or non-thermal, with radial motions and other on-equilibrium manifestations. Activity may be as energetic as in a QSO and as mild as in our alaxy or in M31.

The dividing line between the different groups of AGN is becoming fuzzier as observaional data increase. I believe that the division line between active galaxies and galaxies not ntering AGN is also fuzzy.

Despite the huge amount of work, both observational and theoretical, carried out ately the origin of the required energy (the nuclear engine) is unknown. Interesting suggesions abound, such as accretion flows, mergers, black-holes, tidal interaction and others. I elieve that the power engine is within the nucleus itself, though external effects on a galaxy n general cannot be altogether ruled out. To convince ourselves we can take the case of Seyfert alaxies. The outer regions of these galaxies do not seem to be affected by what happens in the enter. Their spiral forms do not show irregularities any more than in a "normal" galaxy. If the riggering mechanism were extreneous the outer less massive parts, closer to the perturbing body, hould be affected far more than the inner massive nucleus. A detailed study of the morphology nd kinematics of many more Seyfert galaxy spiral structure would help to decide more firmly hether the outer parts are affected by nuclear activity or not. It is plausible that the ctivity in nuclei occurs later in the lifetime of a spiral galaxy. In this connection I refer to a model I have advanced (1963) of the origin of spiral structure, which predicts that spiral arms start forming from the outer towards the inner regions of galaxies (Pişmiş 1963).

Although spectroscopic investigations are actively pursued on AGN's of all kinds, the kinematics and the morphology of these compact objects are as yet not accessible to direct observation. Structures of emission lines and of some absorption lines requires a model for their interpretation. There are however several nearby Seyfert galaxies which have been or can be explored as to their kinematics and morphology. Since the spectra of QSO's are indistinguishable from those of Seyfert 1 nuclei, it is reasonable to expect that the phenomenon of nuclear activity is similar in both cases. Thus, a closer study of nearby Seyfert galaxies should provide valuable hints for the kinematics of QSO's. Implicit is the assumption that kinematic and spectral characteristics are correlated in both classes of objects.

The early work of Walker on NGC 1068 (1968), Seyfert 2, indicated convincingly that the width of the emission lines was caused essentially by the expansion (in general radial motions) of discrete clouds with velocities 300-400 km s^{-1}, and with internal turbulence of the same order (see also Chincarini and Walker 1967). Ulrich (1973) finds that the emission line structure in NGC 4151, Seyfert 2, is due to four clouds expanding away from the nucleus, giving thus support to the discrete cloud model of Seyfert nuclei.

Anderson (1973) however with the same data as Ulrich's argues that motions in the nucleus of NGC 4151 are rotational rather than radial. In the barred Seyfert galaxy NGC 4764 (Rubin *et al.* 1975) spectra at several position angles suggest that just outside the nucleus discrete gas clouds show radial and tangential motions. Evidently the study of high dispersion velocity fields of AGN's is still a fruitful endeavor.

Interesting results from VLA observations on the structure of the inner regions of Seyfert galaxies have been reported (Ulvestad and Wilson 1981; Wilson and Ulvestad 1982). Out of 16 Seyfert and active galaxies, 2 Seyferts have been found to contain double or triple radio sources. NGC 4151 has also a triple source from VLBI observations. Jones, Sramek and Terzian (1981) have detected and studied 15 sources at 18-cm with 6 telescopes. Among these are M51, M81 and M82. Models are developed composed of a small number of components in a region no larger than a few parsecs. These models resemble the hybrid maps of compact sources in QSO's; there is thus indication that a common physical mechanism may be responsible for the existence of compact radio sources in a wide range of objects.

We may state in conclusion that in all well observed Seyferts radial motions in discrete clouds -not isotropic- is inferred. Perhaps some of the answers to questions on compact nuclei should await the launching of the space telescope.

d) *MAGN (Mildly Active Galactic Nuclei).*

Non-circular motions (radially outward or inward) are detected in a number of well observed galaxies which fall outside the conventional AGN group. The radial motions from the nuclear emission lines are usually less than that of rotation. (In few cases a jet may be produced with velocity larger than the rotation). Kinematics of the kind may be taken as a criterion for assignment to a group which I shall call MAGN (for Mildly Active Galactic Nuclei). This group contains thus all galaxies with degree of activity below Seyfert 2's. Clearly the division line between AGN and MAGN's is also fuzzy. I like to emphasize again that, as in many other phenomena in nature, the strength of activity in different nuclei is expected to vary in a continuous manner.

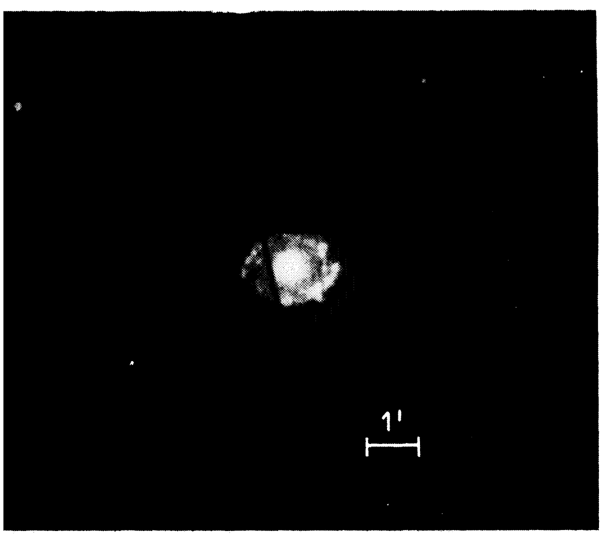
One specimen of MAGN is NGC 253, a large nearby Sc where motions in the nuclear region suggest the outflow of gas towards the observer within a cone (Gottesman *et al.* 1976). Ulrich (1978) has also detected outflow of ionized gas in a similar configuration. Another specimen is NGC 1569 where Pence (1981) has found evidence -using Fabry-Pérot radial velocities- that the galaxy has gone through an eruption 1-2×10^7 years ago.

Higher spatial resolution spectral observations are giving ample evidence that nuclear velocity fields cannot be explained by rotation alone. Radial motions do seem to exist in a large number of presumably "inactive" nuclei. The deviations from pure rotation can be explained either by the special geometry of the nuclear mass, in the form of a fat bar -I am not a partisan of this interpretation- or by outflow or inflow of gas. There is a tendency to overlook the latter alternative, namely the existence of real mass motions and instead to attribute it to the component in the radial direction of the velocities in the elliptical and directed orbits in the presence of a bar potential or oval distortion. In what follows I shall advocate or the existence of radial motions arising from non-gravitational forces unespecified as yet. n some barred galaxies the nucleus has a ring structure. In NGC 1365, NGC 1097 and NGC 4314, o give only three examples, the ring at better resolution is not a closed one but consists of wo tightly wound spirals (see Hubble Atlas for the nuclear spiral in NGC 4314) usually delieated by hot spots. Hot spots have been identified in galaxies searched for by Sersic and Pasoriza (1965). At higher resolution and shorter exposures,one might see whether they are arranged n regular fashion like 'tight spirals' or have an irregular distribution. In NGC 2903 Simkin 1975) suggests the existence of a nuclear ring. It should be rewarding to search for a correlaion of the structure of hot spot assemblies with other physical parameters -Hubble type total ass, mass concentration, etc.- of galaxies. It appears plausible that as we approach QSO's hich have the highest energy outflow, the mass concentration increases.

) *Formation of a Nuclear Spiral.*

I shall comment on a specific nuclear spiral namely that of NGC 4736, where a deailed velocity field shows radial motions as well as rotation (van der Kruit 1976, and referenes therein). The striking bi-symmetry is clearly manifest in Figure 3, which is an enlargement f an Hα interference filter photograph taken with the 2.1-m reflector at the Observatory in an Pedro Mártir.

To explain the morphology and the velocity structure of this tight spiral, we have ssumed that gas outflow occurs from diametrically opposite regions (bi-polar ejection) on the quator of a rotating nucleus and that the ejection velocity is less than that of rotation. The rbits of the ejecta in this case will be ellipses. We have computed the loci of the ejecta ormed 10^7 years after the onset of outflow. Figure 4 shows the double loci thus computed which as a striking resemblance to the nuclear spiral of NGC 4736, (Figure 3). Moreover, the dependen e of the radial motions on position angle observed by van der Kruit (1976) is also explained by ur model. Also in our picture outward as well as inward motions are explained in a direct way or, if after the ejected knots reach the apogalacticon of their elliptical orbits they will be eturning towards the nucleus. At this time they will show inward motions. The fact that our imulation agrees so well with the observed image and the velocity field, is in support of our ssumption that there has been activity in the nucleus of NGC 4736 (Pişmiş and Moreno 1984). The ound image of the nucleus is not compatible with a 'fat bar' which presumably might cause eliptical orbits.



ig. 3. An Hα interference filter photograph of he nuclear spiral in NGC 4736, taken with the .1 meter reflector at the Observatory in San edro Mártir. The scale on the original emulsion s 48 arcsec mm^{-1}.

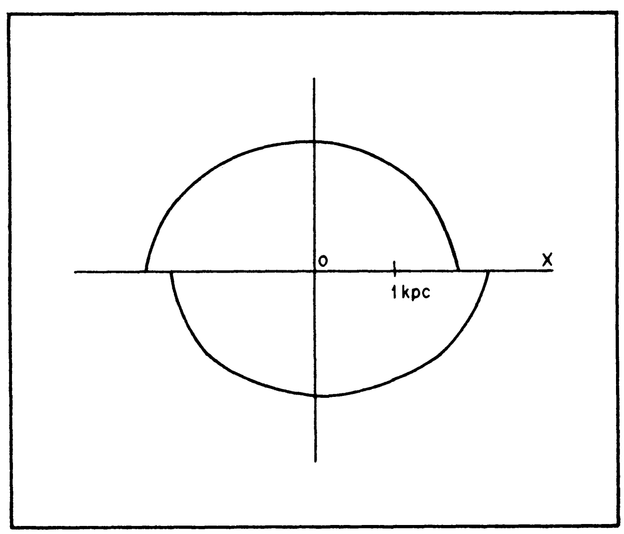


Fig. 4. Nuclear spiral computed with parameters for NGC 4736 given by van der Kruit (1976) to simulate the observed structure and velocity field.

Many more central spirals are likely to be discovered on short exposure images. NG(1300 is suspected to have position-angle-dependent radial motions associated with an inner 'ri (Peterson and Huntley 1980). In summary, I consider the existence of outflow or inflow well es- tablished and this indicates that there is activity in a mild degree in the nuclei of galaxies furthermore, the outflow may be in pulses.

It is reasonable to expect that activity in galactic nuclei is not constant in tim but instead may be decaying or intermittent. It is also conceivable that activity is function physical parameters such as mass concentration at the nucleus. It is worth calling attention t the high contrast of the bulge luminosity to outer regions in NGC 4736 (Sb), a typical MAGN, a in NGC 1068 (Sb) (Seyfert 2). It should be rewarding to search for the frequency of nuclear ac- tivity, however mild, in galaxies with high contrast of center to outer regions.

f) *Overall Properties versus Hubble Type of Galaxies.*

Mass concentration in spirals decreases along the Hubble sequence; this follows fr the fact that R_{max}/R increases from Sa to Scd (from three spirals by Roberts and Rots 1973) wh R is the 'total' radius (Holmberg or de Vaucouleurs radius). Brosche (1973) reached the same conclusion from a larger sample of observations. That V_{max} occurred closer to the center was also suggested by Duval-Chériguène (1976) from rotation curves of 12 barred galaxies.

As to V_{max} itself Brosche (1971) showed that it decreased from Sa through Scd. Thi result is consistent with a decrease of average mass along the Hubble sequence towards later types obtained by using mass estimates from optical as well as 21-cm data (Pişmiş and Maupomé 1978). Figure 5 shows the decreasing trend of the masses. We note furthermore that spiral structure is well developed for average masses larger than $\cong 5\times10^9$ solar masses. For lower masses galaxies are either of the Magellanic type or are irregular; we also note that barred spirals have lower masses than 'normal' spirals for equivalent types.

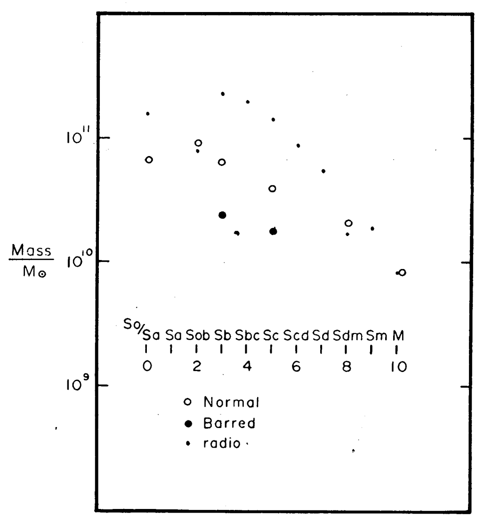


Fig. 5. Relation between Hubble type and average total mass.

Masses determined from 21-cm data a mostly 'indicative', based on the width of th total velocity profile which is equivalent to 2 V_{max}. Figure 5 shows also that the 21-cm ma ses are systematically larger than masses est mated from optical rotation curves, except in irregulars where they are almost the same. Th may be due either to the relatively larger ex tent of the HI or to the different methods us in the mass estimation. In all cases the dis persion around the mean mass is large, which dicates that there is a second independent parameter underlying the Hubble types. Indeed it can be shown that interior to a limiting R where the rotation velocity is V,

$$\mathcal{M}_T \propto V^2 R,$$

where $\mathcal{M}_T$ is the total mass. The second para eter may be either R_{max} or any of those liste earlier.

Tully and Fisher (1971) have shown that the width of the HI profile is an increa ing function of the total luminosity of a spiral. Calibrating the relationship has enab the determination of absolute magnitudes and hence distances to galaxies, independent of redsh

In the last few years optical velocity data on spirals is catching up with the 21- velocities. In a review paper Rubin (1983) discusses the 'systematics of H II rotation curves' with data obtained by Rubin and collaborators on 60 Sa, Sb and Sc galaxies. The main conclusio is that it is the total luminosity that decreases from Sa to Sc and that within a given Hubble type the range of mass is large. On the other hand, it is stated that in a given Hubble type

$\mathcal{M}$/L decreases along the Hubble sequence in the following way: $\mathcal{M}$/L = 6.1 (Sa), 4.4 (Sb) and 2.6 (Sc). (Rubin 1983; Faber and Gallagher 1976). The correlation we have found between mass and Hubble type could therefore be transformed into a decrease of luminosity with Hubble type, albeit a bit faster. Again we would have a large dispersion around the mean luminosities due to the same reason, namely a second independent parameter must be at work, the mass in this case.

A correlation of Hubble type with luminosity is thus equivalent to a correlation with mass. But since mass and hence gravitational forces are overwhelming I think it dynamically more valid to discuss correlations in terms of mass.

It might be rewarding to look into the interrelation of overall properties of spirals with more ample material than the existing ones. Perhaps it may become clear as to which of the parameters underlying the Hubble sequence can conveniently be taken as the second independent one.

Host Galaxies!

Obviously one should study a galaxy globally; there is continuity in nature;one cannot separate the nucleus from the outer parts. It appears that the relative importance of the outer parts diminishes as the nucleus increases in mass and energy. Quasars, the brightest objects known have very tenuous environs if any. Searches carried out with photon counting techniques, CCD or others, have revealed appendages around quasars, some of them resembling spiral structure. It is rather surprising that these appendage are termed 'host galaxies'. Following this trend, should we also call spiral structure a host of the nucleus or of a nuclear bulge?

Epilogue.

A little over sixty years have elapsed since Hubble proposed the morphological classification that bears his name and it is disturbing that we still are unable to interpret it. As data accumulate from all possible regions of the electromagnetic spectrum, the problem becomes more intricate and an overall discussion very difficult. But there is no alternative: a valid model should take into account all observational manifestations.

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Paris Pişmiş: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D.F., México.