THE MOTIONS IN THE CENTRAL REGION OF NGC 4736*

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Abstract. Spectroscopic observations of the central part of NGC 4736 show strong noncircular motions connected with the triple radio source. It is also found that a central ring of H II regions is probably expanding at about 30 km s^{-1}.

1. Introduction

The Sab galaxy NGC 4736 (M94) has a number of interesting features. One of these is the faint external ring that is visible on deep photographs and which will be discussed in more detail elsewhere in this volume (p. 410). I will concentrate here on the central region. Figure 1a shows the galaxy's spiral structure and the central triple

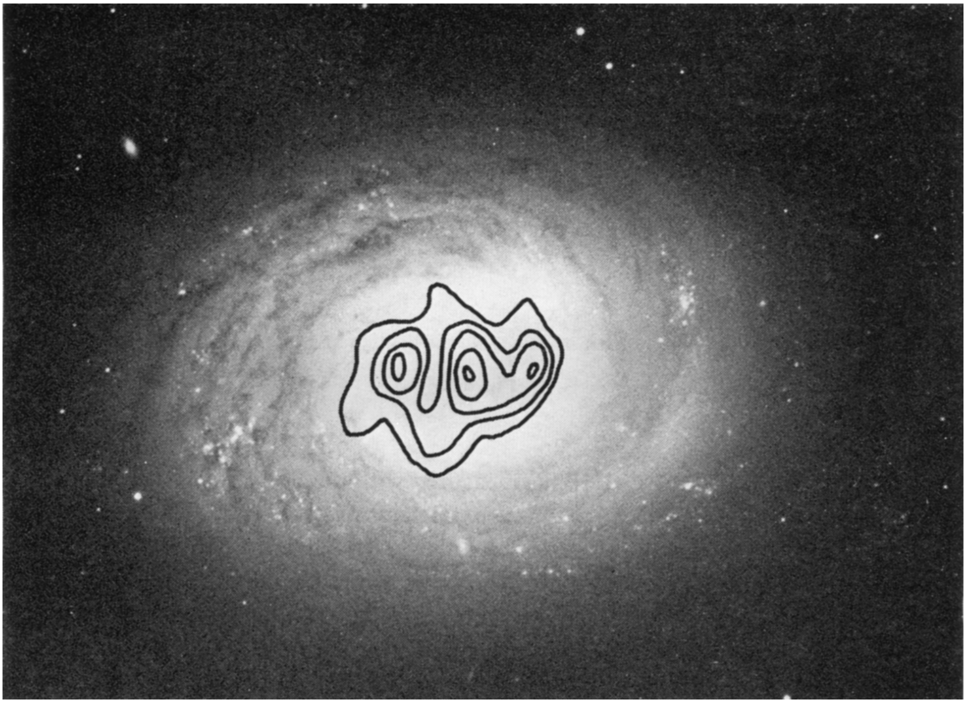

Fig. 1a.

Fig. 1a–b. The various aspects of NGC 4736: (a) The optical disk with spiral structure has an apparent major axis in position angle 107°. The triple radio source is aligned almost east-west. (b) The central ring of H II regions has a major axis in position angle 123° (Hα-interference plate taken with a 200-in. prime-focus image tube; bandwidth from −1600 to +2000 km s^{-1} and exposure time 20 min). The radio source components fall just inside the bright H II regions. In both pictures north is at top and east at left. The scales are 4″12 and 1″44 mm^{-1}, respectively.

* See also: *Astrophys. J.* **188**, 3, 1974.

John R. Shakeshaft (ed.), The Formation and Dynamics of Galaxies. 431–437.

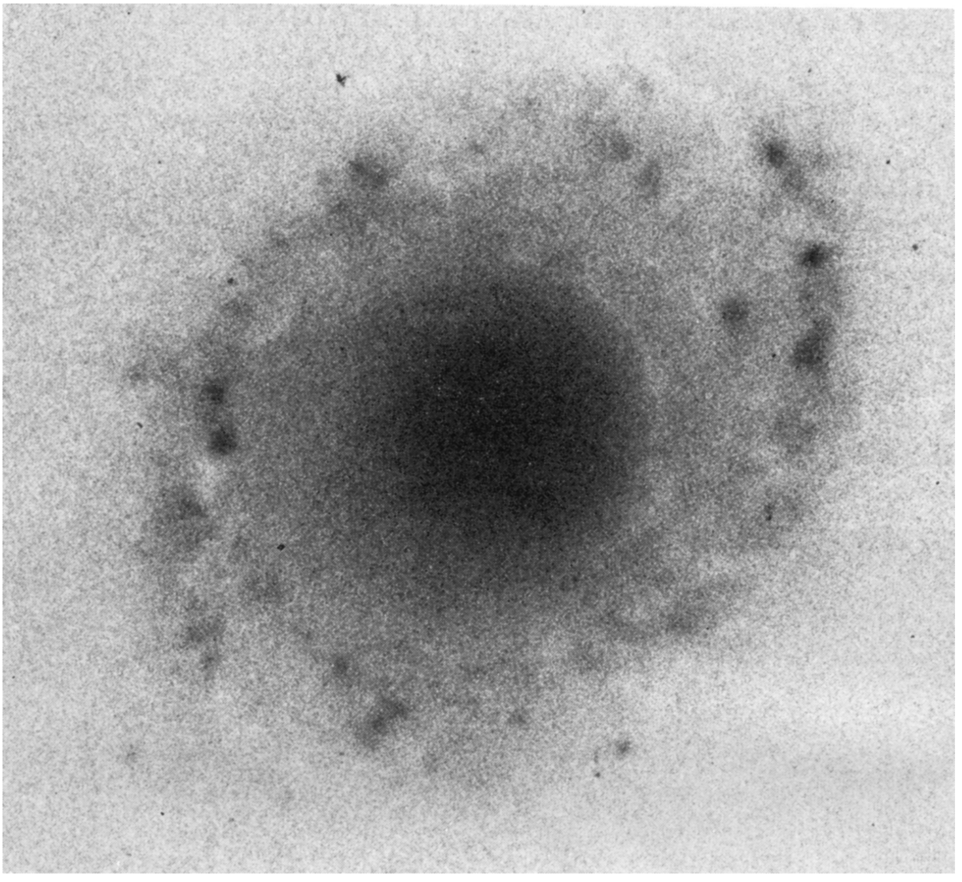

Fig. 1b.

radio source (van der Kruit, 1971b) as measured with the Westerbork synthesis radio telescope at 1415 MHz. The radio source extends nearly east-west. The line of nodes for the plane of the galaxy is in position angle 107° (Burbidge and Burbidge, 1962, [B^2]) as measured from the outline of the optical image of Figure 1a. At a radius of about 50″ from the nucleus there is a 'knotty ring' of H II regions, described by B^2. This is shown in the Hα plate taken at the prime focus of the 200-in. (508-cm) Hale telescope and reproduced in Figure 1b. The 'ring' has an elliptical shape; the position angle of the major axis is 123° (according to B^2) and is markedly different from that of the region in Figure 1a. Just beyond the H II regions there is a very sharp drop in (optical) brightness, described by Sandage (1961), which reinforces the ring-like character of this region. The outer components of the radio complex fall just inside the ring of H II regions. An extensive spectroscopic survey has been made of this inner region in order to determine whether there are effects on the disk of NGC 4736 from the nuclear activity, which is evident from the radio complex.

2. Observations and Velocity Field

The image-tube spectrographs at the Cassegrain foci of the 60-in. (152-cm) and the Hale 200-in. (508-cm) telescopes at Palomar Mountain were used to obtain 22 spectra in 12 position angles on the sky. The spectra were all taken with red gratings; the lines recorded and measured are Hα, [N II] λλ6548, 6583 and [S II] λλ6716, 6731. The emission lines are seen in the 'knotty ring' exclusively and, in agreement with Duflot (1962) and Chincarini and Walker (1967), this region was found to exhibit very small changes in velocity as a function of distance from the centre. This makes it possible to characterize each position angle from the nucleus with one velocity only. A discussion of the errors indicates that the mean error in this velocity ranged from 14 km s^{-1}, if it was derived from one spectrum only, to 8 km s^{-1} if three spectra were available.

On the assumption that the velocity field is symmetric around the nucleus (as Chincarini and Walker show from absorption-line measurements), the systemic velocity of NGC 4736 is $+304 \pm 4$ km s^{-1}, which agrees well with the value of 307 km s^{-1} found from measurements of the 21-cm line emission at Westerbork (Allen, private communication).

The measured velocities as a function of position angle from the nucleus are shown

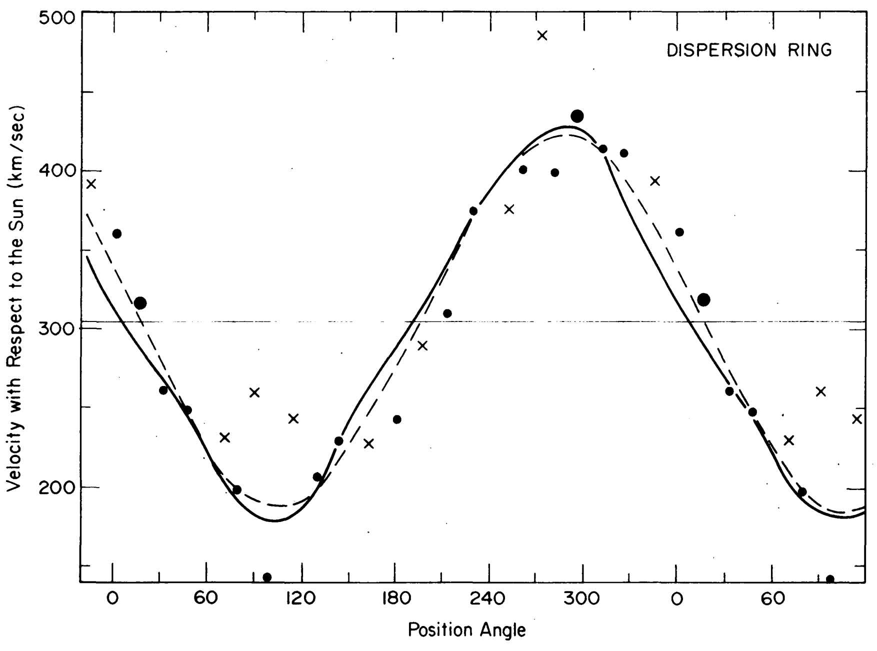

Fig. 2. Observed velocities as a function of position angle from the nucleus and the predicted velocities from the dispersion ring model. The small dots are points derived from one spectrum, crosses from two spectra, and large dots from three. The dashed line is the basic rotation and the full line the total motion in the elliptical dispersion ring. Note that the range of position angle from 0° to 120° has been repeated.

https://doi.org/10.1017/S0074180900024621 Published online by Cambridge University Press

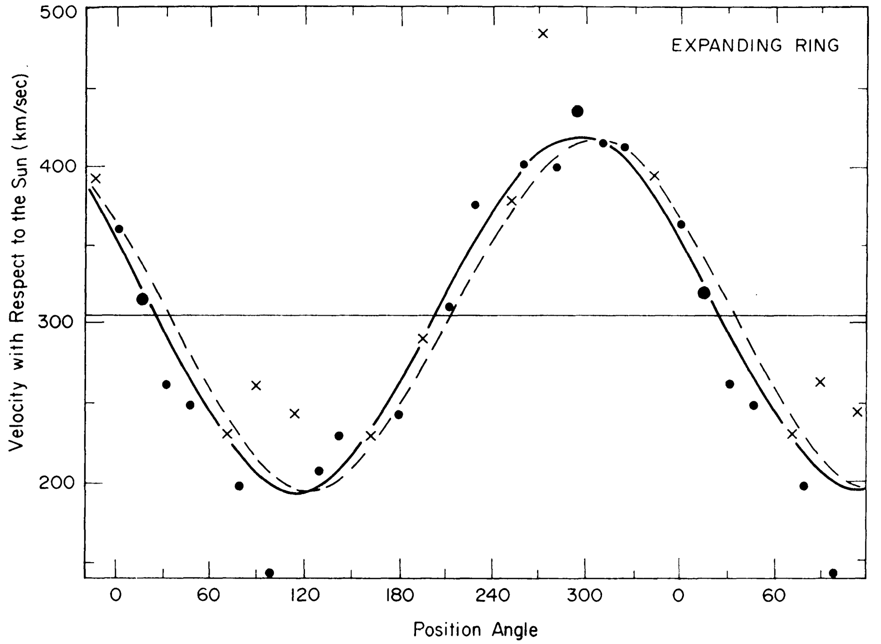

Fig. 3. The same data points with the expanding ring model. The dashed curve is the rotation component only (153 km s^{-1}); the expansion component is 28 km s^{-1}.

in Figures 2 and 3, together with two possible solutions. As can be seen from the figures, the observed points follow the general pattern expected for a rotating ring, except for those in position angles 90°, 100°, 114° and 270°. Since this is the direction of the triple radio source it may be concluded that we are seeing here direct effects of the nuclear explosion on the motions in the disk.

Excluding the measurements at these positions, the best fit to the observed run of velocity with position angle by a field of pure and uniform rotation gives a dynamical major axis in position angle $113° \pm 2°$. This was also found by Chincarini and Walker from spectra in only three position angles. With the present accuracy, however, it is now established that this is significantly different from the line of nodes determined from the shape of the outer regions (107°) and from that determined from the shape of the knotty ring and the accompanying sharp drop in brightness (123°). Also the scatter of the points around the best-fitting sinusoid is not more than is expected from the errors.

3. Interpretations and Discussion

A possible model for NGC 4736 is one in which the line of nodes is in position angle 113° and in which the various apparent major axes are due to perturbations in the structure of the disk. However, a model in which there is such a complicated geometry without noncircular motions of appreciable magnitude is difficult to envisage. Also, the nuclear activity (apparent from the radio sources) and its effects on the disk (at least in the velocity field) suggest the possibility of a causal relation between the ring and the nucleus. I will therefore treat this region in a way similar to that in which the central region of our Galaxy has been explored, namely, in terms of expanding features or of stable, elliptic orbits.

The latter idea was suggested from stellar dynamics by B. Lindblad and has been referred to as a Lindblad resonance or dispersion ring. It has been applied to the central region of our Galaxy by Simonson and Mader (1973), following Shane (1972), and to M51 by Tully (1974). In these cases they fitted the geometry to the observed velocities and indicated a possible solution. Here I will compare the observed velocities with those to be expected from the observed geometry.

The northern side of NGC 4736 is the nearer. This follows from the facts (a) that dust is seen in that side and (b) that the eastern part is approaching, together with the assumption that the spiral structure is trailing. Now if we assume that the line of nodes is in position angle 107° (as indicated by the outer structure) and that the inclination is 40° (from the same outline), the deprojected shape and orientation of the ring can be found and also the predicted velocity field. This is illustrated in Figure 2 where the dashed line indicates the basic rotation and the full line the predicted total velocities. One can see that the 'epicyclic' velocities have components in the line of sight *with the wrong sign*, so that there is clear disagreement between model and observations. It also means that such a model can be made to agree with the observed shape of the ring *and* the observed velocities only if the line of nodes is in a position angle *larger* than 123° or if the southern side were the near side. Neither of these possibilities is very realistic.

Another interpretation is that the ring is close to circular and has a field of radial motions. This means that the line of nodes is in position angle 123° and the inclination is 46°. Figure 3 shows such a fit to the data, where the (uniform) rotation velocity is 153 km s^{-1} and the (uniform) *expansion* velocity is 28 km s^{-1}. The scatter around the line (forgetting about the discrepant velocities in p.a. 90°, 100°, 114°, 270°) is less than in the model with uniform rotation and I conclude that the best model is a circular ring expanding at about 30 km s^{-1} (at least along the apparent minor axis).

I propose that the ring is the result of activity in the nucleus of NGC 4736. This is reinforced by the fact that the outer components of the triple radio source are found close to the brighter H II regions and that strongly deviating velocities are found at these positions. The model for this is expected to be similar to that proposed for the central region of our Galaxy (van der Kruit, 1971a), although there is for NGC 4736 no indication of whether the expulsion took place *in* the plane or at an angle to it. It must also be assumed that the direction of expulsion has been rotating, presumably along with the nucleus.

It is at present not possible to separate the observed velocities into tangential, radial, and perpendicular components, and hence no detailed model for the expulsion or its properties can be given. However, the dimensions and the velocities are comparable to those of the 3 kpc arm in our Galaxy, and consequently most properties, such as the energy involved, expulsion velocities, etc., will be of the same order of magnitude.

The drop in brightness just outside the bright H II regions might be the contact surface between the expanding gas and the quiescent-gas layer. Both the continuum and the emission lines drop in brightness very sharply there and it could easily be a shock region. As in the density wave theory of spiral structure, such a shock might have triggered star formation and given rise to the ring of bright H II regions. It is hoped that subsequent observations will enable a more detailed model to be constructed.

Finally, it is of interest to compare the fit of the dispersion ring model to those in our Galaxy and M51. One can easily check that in both these cases the orientation of the ellipse is precisely that in which the predicted pattern of the velocities in the line of sight is similar to that for an expanding ring. This, and the fact that on the minor axis we always see expansions, make the dispersion ring solution for our Galaxy and M51 rather suspect. It becomes even more so now that NGC 4736 exhibits a case where the observed geometry and velocities are incompatible with that solution.

Acknowledgements

I am grateful to the Carnegie Institution of Washington for a research fellowship and to Dr H. W. Babcock for his hospitality at the Hale Observatories. I also thank the Carnegie Institution for the privilege of receiving the Dr Knut Lundmark Award to permit my travel to Australia.

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DISCUSSION

Miller: Your last slide seems to indicate that the radial velocity data could be explained by a shift in phase that would correspond to a reassignment of the line of nodes. Is your inference of non-circular motion based on data other than the velocity field?

van der Kruit: This shift corresponds to non-zero velocities in the line of sight along the apparent minor axis, which are therefore radial motions. It is exactly this shift which leads to the invocation of expanding motions, because an epicyclic approximation for a dispersion ring would give a different run of the curve *and* a shift in phase in the wrong direction. The inference is thus drawn from a *combination* of data inferred from the velocity field and the observed appearance, and the differences between these two.

Mark: Does the ring connect with the spiral structure further out?

van der Kruit: The spiral structure of NGC 4736 is multi-armed. An inspection of all photographs indicates that part of the 'knotty' structure of the ring might be due to crossing dust lanes, but it is not possible to follow the spiral structure clearly through the ring.

Mark: The density-wave theory can account for such a ring, at the inner Lindblad resonance, without the necessity for an explosion. There is a better theoretical basis for the dispersion ring model, and in addition one finds the peak of ionized hydrogen at 4 to 5 kpc radius in our Galaxy, with a natural explanation in terms of a shock associated with the density wave model.

van der Kruit: In our Galaxy and M 51 it is very difficult to decide between the dispersion ring model and an expansion model, because the geometries are such that the line-of-sight velocities predicted by each are indistinguishable. In NGC 4736, on the other hand, the observed velocities are consistent with an expansion model but not with a dispersion ring model. It is true that this argument depends upon an epicyclic approximation which may not be valid, but nor is there any direct observational evidence that a density wave operates in the multi-armed NGC 4736.