TIGHT NUCLEAR SPIRALS: OBSERVATIONAL EVIDENCE OF NUCLEAR ACTIVITY

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ABSTRACT. It is argued that the tightly wound spiral structure in the nuclei of some galaxies -generally referred to as rings- provides evidence of nuclear activity. It is shown that such spirals are the loci of plasma ejected in a bi-polar fashion from the equator of a rotating nucleus and funneled by a magnetic field. The equation of the loci is derived and applied to the nuclear spiral of NGC 4736. The observed rotational and angle-dependent ejection velocities, as well as polarization of non-thermal continua give support to our model.

1. INTRODUCTION

We may define activity in the nuclei of galaxies as a phenomenon which deviates from a steady state. Ejection of matter is one such phenomenon. Systems of galactic size which show non-equilibrium manifestations in their centers are being studied intensively under the heading AGN (Active Galactic Nuclei). Objects that are included in the AGN group range from the spectacular quasars, radio galaxies, BL Lac objects down to Seyferts 1 and 2. Milder cases of activity fall outside the AGN group and they are often ignored or considered as anomalous.

Pişmiş has argued earlier that all galaxies show activity with differing scales of power. The activity may be as energetic as in a quasar ($\sim 10^{46} - 10^{47}$ ergs s^{-1}), intermediate as in a Seyfert 2 or as mild as in M31 or in our Galaxy, nearly all showing variability (Pişmiş 1987).

We believe that milder cases of activity in the nuclei of galaxies not entering the AGN group may afford useful information toward the study of the physics of non-stationary nuclei. It is conceivable that the central "engine" is a universal one, and that it is the large range of nuclear power which manifests itself along the sequence of activity from the strongest AGN, to the mildest.

We have proposed tha acronym MAGN to denote all nuclei with activity milder than Seyfert 2's (Pişmiş 1985, 1987); M stands for "mildly". The intention has not been to introduce a new terminology but rather to emphasize that studies of activity should not terminate at Seyfert 2's but should continue down to the least active cases. Evident-

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tly it is advisable to study in detail some specimens throughout the whole sequence of activity if we are to decipher the origin and evolution of AGN.

Here we shall consider one particular type of object in our MAGN group, mostly early SB's, in the bright nuclei of which a small tight spiral structure is detected 1-2 kpc from the center, usually studded with H II condensations (hot spots). Such structures are loosely termed "rings". But a close look almost always reveals symmetrical breaks diametrically opposite with respect to the center. At better resolution they are indeed tight spirals. An example of a nuclear spiral,is that of NGC 4314 (SBb/pec), (see Hubble Atlas). Other galaxies of the kind are NGC 613, 1097, 1365, 1512.

Such objects were classified as peculiar but upon better resolution a small spiral is detected; it appears that the existence of a central spiral within the bright nucleus of an SB galaxy is the rule rather than the exception. The "S-shaped configurations" in the center of galaxies mentioned often in current literature are probably a pair of tight spirals seen at low resolution. A systematic search for structure of the kind in the nuclei of barred galaxies should be rewarding.

In what follows we shall demonstrate that matter ejected from two regions situated diametrically on the equator of a rotating nucleus (bipolar ejection) describes, t years after the onset of ejection, a locus which is a tightly wound spiral. Two such symmetrical loci simulate not only the morphology but also the observed velocity structure as will be shown presently.

2. FORMALISM

A tight spiral is the locus of matter ejected from a rotating nucleus.

Assume the nucleus to be a mass point. Let R and θ be the polar coordinates with origin at the mass point, V, the velocity of ejection, Ω the angular velocity of rotation; R_0 is the radius vector of the ejection point, and is assumed to be constant throughout the ejection.

The eccentricity of the orbit of the ejecta (a conic section) is

$$e = \frac{V}{\Omega R_0} \quad . \tag{1}$$

If a is the semi major axis of the conic section, clearly

$$\frac{a}{R_0} = \frac{1}{1-e^2} \quad . \tag{2}$$

After some lengthy algebra we obtain the equation of the locus of the ejecta produced after a period of time t from the onset of ejection as follows:

$$\theta = \arccos \frac{1}{e}\left(1 - \frac{R_0}{R}\right) - \left(\frac{a}{R_0}\right)^{3/2} \left(e\,|\cos\alpha| + \alpha + \frac{\pi}{2}\right) \tag{3}$$

here $\alpha = \arcsin \frac{a-R}{ea}$;

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the time t is given by $t = \frac{\theta}{\Omega}$.

Observations available to date of tight spirals show that the velocities in the radial direction are less than that of rotation (otherwise the observed spiral would not have a ring-like form). Thus our model requires that the maximum distances attained by the ejecta not exceed the maximum observed distance of the spiral from the center of attraction. This requirement ensures that the orbits of the individual ejecta be ellipses: $0 < e < 1$.

In an earlier paper we have obtained the loci mentioned above by numerical integration (Pişmiş and Moreno 1984). To compare the two procedures to obtain the loci we have adopted values for the pertinent parameters as follows: $e = 2/3$, $R_0 = 0.8$ kpc. R_{max} and R_{min} will now be 2.35 and 0.48 kpc respectively. With this choice of parameters the loci obtained from equation (3) can be compared directly with case 1 of our previous work.

The locus computed from expression (3) is identical to that computed earlier (Pişmiş and Moreno 1984). That locus is presented in Figure 1. For each point marked on the spiral curve we give, in parenthesis, the computed velocities of expansion and rotation respectively.

Application to a Concrete Case.

NGC 4736 although not a barred galaxy has a nuclear spiral de-

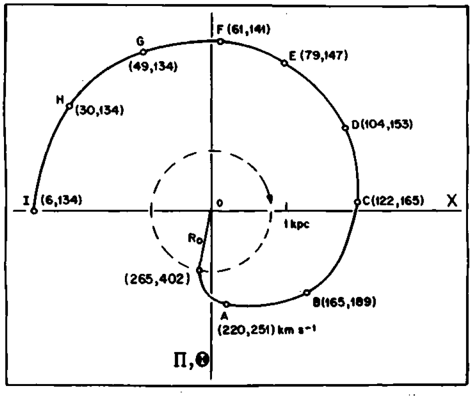

Fig. 1. Locus of the ejecta from a rotating nucleus. The figure spans 3.5×10^7 years from the onset of ejection to the present ejection from R_0. The numbers in parenthesis indicate the radial (π) and tangential (θ) components of the velocity.

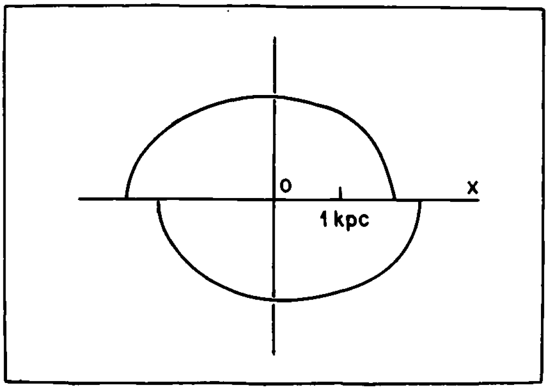

Fig. 3. Two symmetrical tight spirals formed by ejection from the ends of a diameter of a galactic nucleus. The curves are sections covering 180° of the locus of Figure 1 and are projected by 40° to the plane of the sky.

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lineated by H II condensations. It is nearly 4 kpc across, larger than those associated with SB galaxies. However, a very detailed velocity field is given by van der Kruit (1976); this circumstance prompted us to make a comparison of our loci with the nuclear spiral of that galaxy. Figure 2 is an Hα interference filter image of the central spiral of NGC 4736 taken with a focal reducer attached to the Cassegrain focus of the 2.1-m reflector of the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California. Figure 3 represents two spirals computed by expression (3) symmetrically placed but spanning only 180°, and inclined to the tangent plane by 40°, the inclination estimated for NGC 4736. The resemblance of the sketch to the image shown in Figure 3 is striking.

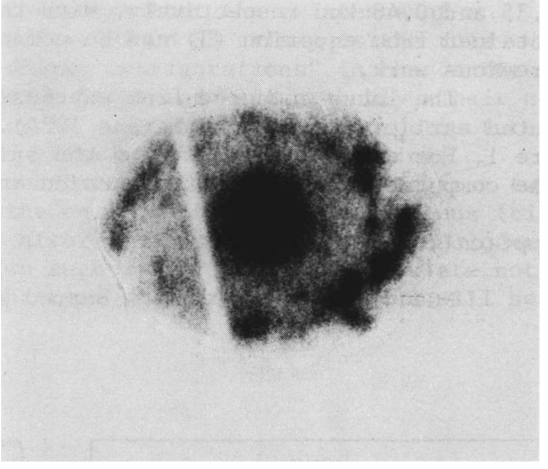

Fig. 2. Enlargement of an image tube Hα photograph of the central spiral of NGC 4736 taken with a focal reducer attached to the Cassegrain focus of the 2.1-m reflector of the Observatorio at San Pedro Mártir, México. The scale on the original film is 49 arcsec mm^{-1}. The dark streak is the shadow of a metal reticule inherent in the equipment.

Regarding the time needed to produce the spiral locus, with an assumed value of the rotational velocity, θ_0 = 150 km s^{-1} at R_0 = 0.8 kpc, we obtain an age of 3.5×10^7 years for the spiral shown in Figure 1. The duration of the ejection is a parameter which can change not only the sense of radial motions (inward or outward) but also the morphology of the spiral.

Following the onset of ejection the outward velocity of matter -which may be in the form of blobs- will diminish until it becomes zero when a blob reaches the apogalacticum of its elliptical orbit. From there on radial motions will be clearly inward, increasing gradually. Our model explains, thus, not only the outward motions but inward motions as well; in fact, of the galaxies showing radial motions in their nuclear regions, inward or outward motions are equally frequent (Pişmiş 1979). Moreover, the radial motions will be dependent on the position angle of the blobs. In particular, Jörsäter finds a clear dependence of outward velocities with position angle in NGC 1512 (SB(r)a), the range of the velocity difference being about 50 km s^{-1} within a span of PA 20° (Jörsäter 1979).

It is worth noting that in our model inward and outward motions may coexist in the same galaxy. High precision velocity data with high spatial resolution of many more galaxies are desirable for further support to our model.

3. DISCUSSION

So far we have assumed the bi-symmetry of the ejection of gas from a rotating nucleus without mentioning the agent funneling the ejecta. As in earlier work (Pişmiş 1961; for a summary see Pişmiş 1979; Pişmiş and Moreno 1984) we again postulate the existence of a magnetic field within the nucleus with parallel lines of force and all perpendicular to the axis of rotation. To represent the situation phenomenologically we approximate the field to that of a dipole centrally situated and perpendicular to the rotation axis. The plasma, nearly frozen in will flow out preferentially through the magnetic polar regions, giving rise to the bi-symmetry.

Our model does not take into account the presence of interstellar matter in the surroundings of the nucleus. The existence of the latter may distort the ellipses described by the ejecta. The representative eccentricity of these ellipses is expected to diminish. If the IS material is reasonably homogeneous the opposing forces of friction on the outgoing mass will not alter the spiral appearance of the locus. The spiral may be even tighter than the one without the frictional forces. In such case one may afford to have a larger ejection velocity and still simulate the observed spiral.

We have also neglected magnetic forces; magnetic lines of force at the polar regions of the postulated magnetic dipole, and which are frozen in the plasma, will resist to bending as the ejected plasma is left behind while the nuclear plasma rotates. The representative eccentricity of the resultant "ellipses" will therefore tend to increase. Evidently this mechanism works in the opposite sense from the one caused by friction of the outlying interstellar matter. Thus the two effects may compensate one another such that the shape of the spirals may not be altered appreciably.

A detailed overall treatment of the consequences of ejection and rotation should take into account a number of other phenomena: the balance between the angular momentum lost to, and that which remains in the nucleus. The radius and the mass of the ejecting nucleus are expected to change as well. The magnetic flux may also vary due to ejection and to decay.

At this stage we do not enter into sophisticated treatment of the points raised in the previous paragraph nor consider interaction of the ejecta with the ambient matter. It is quite reasonable to expect that these effects are of second order compared with gravitational effects and that their neglect will not conceal the tight spiral trend of the loci.

We may state therefore that symmetrically located spiral structures usually delineated by "hot spots" in the central regions of galaxies may be engendered by ejection of plasma from a rotating nucleus. The bi-symmetry of the spiral features is presumably caused by a centrally located magnetic field.

It is interesting to note that for the SBb galaxy NGC 4314 at the nucleus of which a tight spiral is clearly observed, (Fig. 1) VLA observations in the 6 and 20-cm continua have shown that the radiation is essentially non-thermal and that polarization vectors (at 20-cm) are consistent with the existence of magnetic lines of force along the tight spiral (García-Barreto and Pişmiş, 1986, 1987).

We can therefore state that on the one hand the morphology of the central spiral and on the other, the angle dependence of the radial motions, give strong evidence that activity in the form of bi-symmetrical ejection of plasma has occurred in the nuclei of galaxies where a tight central spiral is present.

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