Minor-Axis Stellar Velocity Gradients in Disk and Polar-Ring Galaxies

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1. Introduction

Kinematical decoupling between two components of a galaxy suggests the occurrence of a second event. In disk galaxy it is usually observed as a counterrotation of the stellar disk with respect to the gaseous component and/or with respect to a second stellar disk. We discuss here three cases of kinematical orthogonal decoupling of the innermost region of the spheroidal component with respect to the disk or ring component in two Sa spirals and in an elliptical galaxy with a polar ring.

2. The Case Galaxies

2.1. NGC 4698
NGC 4698 is classified Sa by Sandage & Tammann (1981) and Sab(s) by de Vaucouleurs et al. (1991, RC3). Sandage & Bedke (1994, CAG) in The Carnegie Atlas of Galaxies presented NGC 4698 in the Sa section as an example of the early-to-intermediate Sa type. They describe the galaxy as characterized by a large central E-like bulge in which there is no evidence of recent star formation or spiral structure. The spiral arms are tightly wound and become prominent only in the outer parts of the disk.

As discussed by Bertola et al. (1999), this galaxy is characterized by a remarkable geometric decoupling between bulge and disk, whose apparent major axes appear oriented in an orthogonal way at a simple visual inspection of the galaxy images (e.g., Panels 78, 79 and 87 in CAG). The R–band isophotal map of the Sa galaxy NGC 4698 shows that the inner region of the bulge structure is elongated perpendicularly to the major axis of the disk (Fig. 1), while the outer structure is perpendicular to the disk if a parametric bulge-disk decomposition is adopted. The bulge tends to become rounder, but never elongated along the disk major axis, using a non-parametric decomposition.

The stellar velocity curve measured along the major axis of NGC 4698 is characterized by a central plateau, indeed the stars have a zero rotation for \( |r| \leq 8'' \) (Fig. 2). At larger radii the observed stellar rotation increases from zero to an approximately constant value of about 200 km s\(^{-1}\) for \( |r| \geq 50'' \) up to the farthest observed radius at about 80''. We measured the minor-axis stellar kinematics out to about 20'' on both sides of the galaxy. In the nucleus the stellar velocity rotation increases to about 30 km s\(^{-1}\) at \( |r| \approx 2'' \). Then it decreases between 2'' and 6'' and it is characterized by an almost zero value beyond 6''. The ionized-gas velocity field, which is presented here for the first
time (Fig. 2), is characterized by a velocity gradient along the major axis higher than that of the stars. Along the minor axis the gas velocities closely match those of the stars. This suggests that this gas is associated to the stars giving rise to the minor-axis velocity gradient. These observations point out to the presence in NGC 4698 of two gaseous and stellar components characterized by an orthogonal geometrical and kinematical decoupling.

2.2. NGC 4672

NGC 4672 is an highly-inclined early-type disk galaxy classified Sa(s) pec sp in the RC3. It is characterized by an intricate dust pattern crossing the bulge near its center. As for NGC 4698, the bulge of NGC 4672 appears elongated in an orthogonal way with respect to the disk as shown by its $R$–band isophotal map (Fig. 1). Whitmore et al. (1990) considered NGC 4672 a possible candidate for an S0 galaxy with a polar ring. However, as discussed in more detail by Sarzi et al. (1999, in this volume), there are a number of evidences indicating that NGC 4672 is a spiral galaxy.

The major-axis stellar velocity curve is characterized by a central plateau of zero rotation (Fig. 2). The minor-axis stellar velocity curve shows a steep gradient in the nucleus ($|r| \leq 2''$), rising to maximum of about 80 km s$^{-1}$. At larger radii the velocity tends to drop to a zero value. The major-axis ionized gas velocity curve (extending to about 60'' from the center on both sides of the galaxy) is radially asymmetric. No significant gas rotation is detected along the minor axis for $|r| < 6''$.

Also in this case a kinematical orthogonal decoupling between the inner stellar component and the disk is present.
Figure 2. Stellar (filled symbols) and ionized-gas (open circles) kinematics along the major (left panel) and minor (right panel) axis of the disk (or ring) of NGC 4698, NGC 4672 and AM 2020-504. In the plot 1'' corresponds to 56, 193, and 325 pc for NGC 4698, NGC 4672 and AM 2020-504, respectively (assuming $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$). The stellar kinematics of NGC 4698 is taken from Bertola et al. (1999). The observations of NGC 4672 are from Sarzi et al. (1999, in preparation). For AM 2020-504 the open circles and filled squares are new data, the filled circles and the solid line represent the stellar velocities measured by Whitmore et al. (1990) and Arnaboldi et al. (1993a), respectively.

2.3. AM 2020-504

This galaxy is considered the prototype of ellipticals with polar ring. It is constituted by two distinct structures: a mostly gaseous ring and a spheroidal stellar component (E4) with the major axes perpendicular each other. It has been extensively studied by Whitmore et al. (1990) and by Arnaboldi et al. (1993a,b).

The most characteristic feature of the stellar kinematics of AM 2020-504 is the presence of a velocity gradient along the major axis of the spheroidal component and consequently perpendicular to the ring major axis. This gradient has been observed by Whitmore et al. (1990) and Arnaboldi et al. (1993a) and confirmed by us (Fig. 2). The high-resolution spectrum by Arnaboldi et al. (1993a) shows a rise of the velocity up to about 130 km s$^{-1}$ at $r \approx 4''$ followed by a decline to zero velocity outside 10''. This, together with the zero velocity we observed within $|r| < 3''$ along the ring minor axis, indicates a rotation around the minor axis. Our velocity curve of the gas along the disk major axis is in agreement with that of Whitmore et al. (1990). The warped model for the
gaseous component discussed by Arnaboldi et al. (1993a) predicts a velocity gradient along the minor axis of the ring, which is not shown by our data.

3. Discussion

In spite of their morphological differences, the three galaxies described in the previous section share two common characteristics:

(i) The major axis of the disk (or ring) component forms an angle of 90° with the major axis of the bulge (or elliptical) component. This orthogonal geometrical decoupling is quite uncommon among spiral galaxies.

(ii) The stellar kinematics along the disk minor axis indicates the presence of a kinematically isolated core, which is rotating perpendicularly with respect to the disk (or ring) component.

At this point we ask ourselves whether these galaxies also share similar formation processes. Arnaboldi et al. (1993a; see also Sparke 1986) suggest that in AM 2020-504 the material forming the ring has been accreted into polar orbits by an oblate elliptical. The decoupled core may represent material which has settled down in the symmetry plane of the oblate spheroidal galaxy at the beginning of the acquisition process, and subsequently has turned into stars.

If this mechanism produced also the kinematically isolated stellar cores in the two spirals NGC 4698 and NGC 4672, then the geometrical orthogonal decoupling observed in these galaxies results from the fact that the disk moves in polar orbits around the central oblate spheroid. No velocity gradient along the disk minor axis and no geometrical decoupling are expected if the acquisition process produces a disk settled on the equatorial plane of the spheroidal component. The rarity of bulges which are perpendicularly sticking out from their disks would suggest that the case of equatorial acquisition is the most common one.

The above considerations lead us to face a scenario in which the disk of a spiral galaxy might have been formed as a second event by accretion around a pre-existing bare spheroid.

References