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THE COUNTERROTATION OF GAS AND STARS IN THE DUST LANE ELLIPTICAL NGC 5898[1]

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ABSTRACT

In this paper we show that in the spectrum of the elliptical galaxy with inner dust ring NGC 5898 the emission lines are inclined in the direction opposite to that of the absorption lines. Since the projected major axes of the stellar and gaseous component are coincident, the most likely interpretation of the phenomenon is that the angular momenta of the two components are antiparallel. This implies that the dust ring is a second event in the history of NGC 5898 and reinforces the idea that the dust lanes in ellipticals are generally the result of an acquisition.

Subject headings: galaxies: individual (NGC 5898) — galaxies: internal motions — galaxies: photometry

I. INTRODUCTION

The presence of kinematical decoupling between the stellar and gaseous components in elliptical galaxies with emission lines has been pointed out in a number of cases (Bertola *et al.* 1984 and references therein). The phenomenon is particularly remarkable in the elliptical galaxies with a dust lane along the minor axis, where the stellar and gas angular momentum vectors are perpendicular (Bertola, Galletta, and Zeilinger 1985; Bertola 1986 and references therein). This fact is a strong indication that the two components do not have the same origin and therefore that the dust lane represents a second event in the history of the galaxy. It would then most likely be the result of an acquisition of material by the elliptical. Indeed, according to the classical picture of galaxy formation, all the gas will rotate in the same sense, after an appropriate time, due to the exchange of angular momentum in the protogalaxy. Therefore if coeval gas is observed, this would rotate in the same way as the stars. Thus when a decoupling of the angular momenta occurs, this implies an external origin for the gas. The models of Tubbs (1980) and Simonson (1982) describe the possible mechanism for acquisition, independently of whether the warped dust structures observed in these galaxies are transient or stationary phenomena. Decoupling is not expected only in the case of slow accumulation of a massive disk (Binney and May 1986). Orthogonal angular momenta, indicating that the gaseous ring is a second event, are also typical of polar ring galaxies (see, e.g., Richstone and Potter 1982; Whitmore, McElroy, and Schweizer 1987; and van Gorkom, Schechter, and Kristian 1987).

The acquisition hypothesis, however, is not completely tested until the gas is "found" rotating not only perpendicularly, but also in the direction opposed to that of the stars.

In this paper we present observations of NGC 5898 which is the first case of a dust lane elliptical where the gas is counterrotating with respect to the stars. A previous case of counterrotation in an elliptical with gas (but without dust lane) has been described for NGC 7097 by Caldwell, Kirshner, and Richstone (1986). Retrograde gas streaming was also found by Galletta (1987) in the disk galaxy NGC 4546.

NGC 5898 was originally classified E0 by de Vaucouleurs, de Vaucouleurs, and Corwin (1976). This was later changed to SABO- (Corwin, de Vaucouleurs, and de Vaucouleurs, 1985) and $S0_{2/3}(0)$ (Sandage and Tammann 1981) after the discovery of a dust lane. The dust lane, with the appearance of a ring inclined 40° to the line of sight (if circular), was first described by Sparks *et al.* (1985), who also published an image of it. The major axis of the ring, which extends 30″ in diameter, lies at P.A. = 5°. The absolute magnitude of NGC 5898 is $M_B = -20.6$ ($H_0 = 50$ km s^{-1} Mpc^{-1}) from its redshift of 2160 km s^{-1} (this paper), and apparent magnitude $m_B = 12.6$ (de Vaucouleurs, de Vaucouleurs, and Corwin 1976). NGC 5898 lies 5′ from the E2 galaxy NGC 5903, and the difference in radial velocity between the two galaxies is 250 km s^{-1}. A small companion, whose velocity is not available, is present at 0′.3 north of the galaxy.

NGC 5898 has been detected by *Einstein Observatory*, and the X-ray flux is commensurate with its blue luminosity (Trinchieri and Fabbiano 1985).

No H I has been detected in this galaxy, although several H I clouds are observed in the field (Appleton *et al.* 1985).

II. OBSERVATIONS AND DATA REDUCTION

During 1984 March five spectra (exposure 60 minutes each) of NGC 5898 and two of template stars were obtained with the ESO telescopes at La Silla at different position angles using the image tube + B&C spectrograph. Two were obtained with the 3.6 m telescope (P.A. = 60° and 150°, dispersion = 39 Å mm^{-1}, scale = 37″ mm^{-1}) and three with the 1.52 m telescope (P.A. = 0°, 30°, 90°, dispersion = 39 Å mm^{-1}, scale = 87″ mm^{-1}). The spectra were digitized with the ESO PDS microdensitometer with an aperture of 12.5 × 50 μm. All the spectra were calibrated in intensity and wavelength using the IHAP system at Garching. More recently on 1987 May 3, an additional spectrum at P.A. = 150° has been obtained with the B&C spectrograph + CCD at the ESO/MPI 2.2 m telescope

[1] Based on observations collected at the European Southern Observatory, La Silla, Chile.

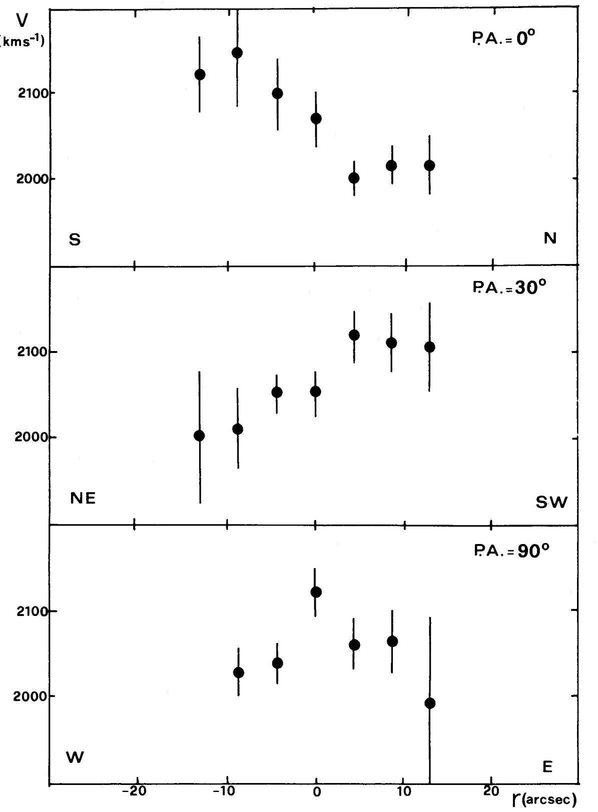

FIG. 1.—Velocity curves for the stellar component at different position angles.

(exposure 90 minutes, dispersion = 59 Å mm^{-1}, scale = 59″ mm^{-1}). The image-tube and CCD spectra cover the blue and yellow region of the spectrum, respectively. All the calibrated spectra were finally analyzed with the Fourier quotient method (Bertola *et al.* 1984) at the Padova Observatory Computing Centre in the spectral range λλ3900–4500 for the image tube spectra and λλ4900–5700 for the CCD data. In this way we obtained simultaneously the radial velocity V_r, the velocity dispersion σ, and the line strength parameter for the absorption lines at different heights along the slit.

The [O II] λλ3727–29 doublet, which appears blended, and the [O III] λ5007 emission line were measured on the 3.6 m image-tube spectra and on the CCD spectrum respectively. A noninteractive batch IHAP program which fits Gaussian profiles to the lines for each scan line has been used. The resulting velocity curves for the absorption and emission lines are plotted in Figures 1 and 2.

In addition to the spectroscopic data, two *R* (exposure 5 and 15 minutes) and one *B* (exposure 5 minutes) frames were recorded with the 320 × 512 RCA CCD of the 2.2 m ESO/MPI telescope on the night 1987 January 1/2. All the frames were corrected for flat-field and bias and sky-subtracted in order to be analyzed with the INMP package (Barbon, Benacchio, and Capaccioli 1975) and to obtain the photometric parameters of the isophotes.

III. RESULTS

The stellar velocity field in the central region is characterized by a maximum slope of 10 km s^{-1} arcsec^{-1}, V_{max} = 80 km s^{-1} at PA = 150°. This slope and those at the remaining position angles are consistent with a sinusoidal representation (as a

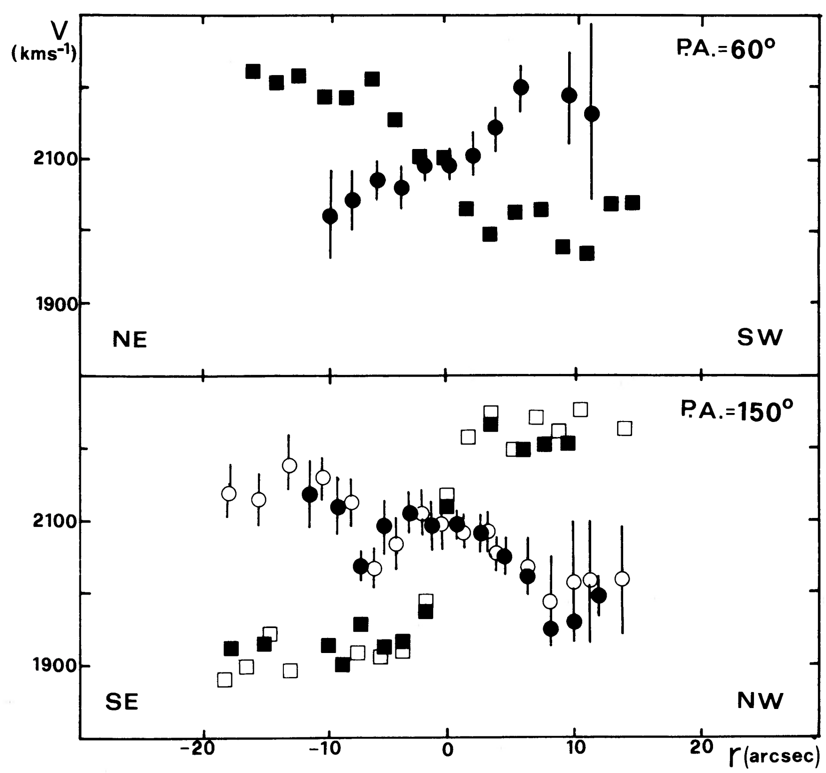

FIG. 2.—Velocity curves for stellar (*dots*) and gaseous (*squares*) components at different position angles. Open and full symbols refer to the CCD and 3.6 m image-tube spectra, respectively. Error bars are from the Fourier quotient method. The error of the emission lines measurements is about 25 km s^{-1}.

function of the position angle) with a maximum amplitude not far from the major axis of the dust ring. This indicates that the projected rotation axis of the stellar component coincides with the minor axis of the dust ring.

The velocity dispersion in NGC 5898, as derived with the Fourier quotient method, is constant in the inner regions and the following mean values are derived 216 ± 15 km s^{-1} for the three spectra obtained with the 1.5 m telescopes and 240 ± 6 km s^{-1} for the two spectra obtained with the 3.6 m and 240 ± 8 km s^{-1} for the 2.3 m spectrum. We shall assume a value of $\sigma = 230$ km s^{-1} for the central velocity dispersion in NGC 5898. The resulting value of V_{max}/σ is 0.35. Since the galaxy is almost round, the location of its representative point in the V_{max}/σ versus ϵ diagram falls close to the line of the oblate isotropic rotators. The galaxy follows closely the L versus σ^4 relation (Faber and Jackson 1976).

The velocity curves of the gas component in NGC 5898 are available at P.A. 60° and 150°. The central slope is higher at P.A. 150° which is closer to the major axis of the dust ring which, from the image of Sparks *et al.* (1985), is estimated to lie at P.A. = 5°. In the spectrum at P.A. 150° the turning point of the velocity curve is well determined and gives $V_{max} = 175$ km s^{-1}. On the reasonable assumption that the ring is rotating like a disk we deduce that the maximum projected velocity of rotation at P.A. 5° is $V_{max} = 210$ km s^{-1}. Taking into account the inclination of the ring of 40° to the line of sight one gets $V_{max} = 260$ km s^{-1}.

The remarkable fact about the absorption and emission velocity curves at P.A. 60° and 150° (Fig. 2) is that the sense of rotation of the stars is opposite to that of the gas.

We have used the more exposed CCD red image in order to derive the trend of the ellipticity and of the position angle of the isophotal major axis (Fig. 3). The blue image gives similar results, which are in turn in very good agreement with those of Sparks (1987). Rapid changes in both curves occur in the inner regions, and it is not clear whether they are caused by the presence of the dust lane. Unfortunately in our frames a hot column is present exactly where the dust lane is stronger, so we were unable to visualize it in our frames.

The B luminosity profile in the region from 2″ to 80″ from the nucleus is well represented by an $r^{1/4}$ law with $r_e = 23.6$ and $\mu_e = 22.7$ mag $arcsec^{-2}$. With the adopted distance, the total B luminosity is $L_T = 1.3 \times 10^{10} L_{\odot}$.

The rotation curve of the gas component allows us to derive the mass distribution within this galaxy. The latter has been derived on the simplifying assumption of spherical symmetry and compared with that of the light derived using Young's (1976) tables under the same assumption. The mass of the galaxy within the last measured point at 20″ is $M = 4.5 \times 10^{10} M_{\odot}$. The corresponding luminosity $L(20″)$ is $5.9 \times 10^9 L_{\odot}$

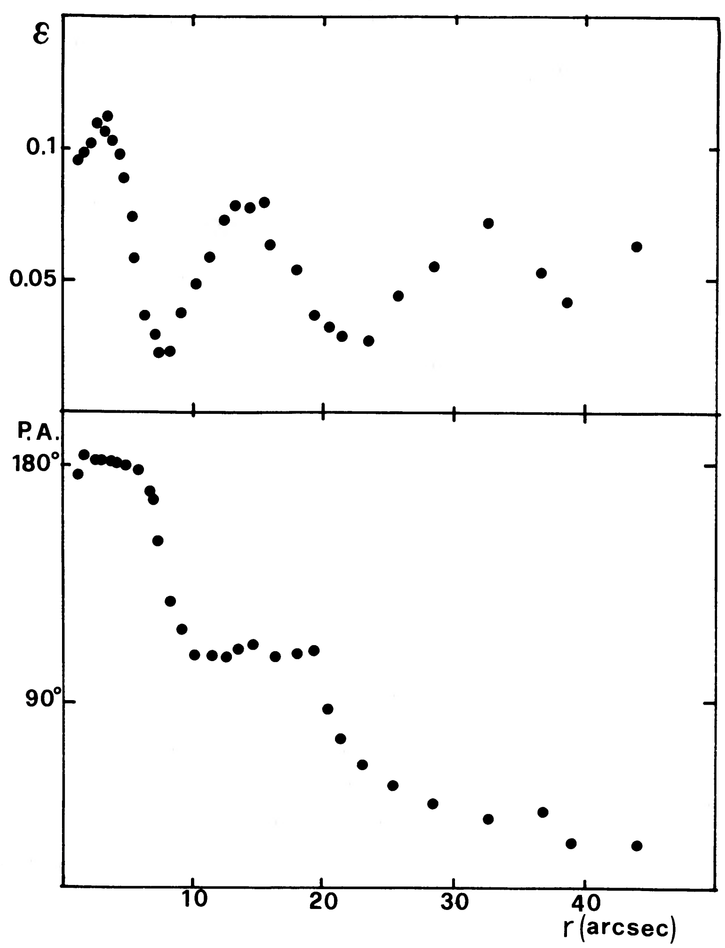

FIG. 3.—Ellipticity and position angle of the major axis as a function of the equivalent radius from the red CCD image

indicating an integrated value of M/L_B within 20″ of 7.6. Inner values of M/L_B are 4 and 7 within 5″ and 10″, respectively. This increasing trend of M/L_B is similar to that found in NGC 7097 (Caldwell, Kirshner, and Richstone 1986) and in several other ellipticals (Bertola *et al.* 1987).

IV. DISCUSSION

Given the small degree of flattening observed for this galaxy and the rapid twisting of the isophotes, it is difficult to classify this galaxy as a major, minor or skew dust lane elliptical.

If NGC 5898 is an oblate elliptical or disk galaxy, we deduce that the ring does not lie in the principal plane of the galaxy and therefore is not in a stable position. We conclude this from the observed misalignment of the major axis of the outer isophote (P.A. = 50°) and of the dust ring (P.A. = 5°) supposed to be circular. Since a regular structure like a ring is unlikely to be a transient phenomenon, we must rule out the oblate shape. This is also indicated by the high value of (projected) $V_{max} = 80$ km s^{-1} of the stellar component. When deprojected, taking into account the apparent flattening which indicates a 73° inclination of the principal plane of the galaxy with the line of sight, it becomes $V_{max} \approx 300$ km s^{-1}, a value much too high for an elliptical and even for a disk galaxy.

In the previous section we have shown that in the spectra of NGC 5898 at P.A. = 150° and 60° a unique phenomenon among dust lane ellipticals occurs, namely that the absorption and emission lines are tilted with opposite inclination. This implies that the angular momenta of the stellar and gaseous components as projected on the sky are antiparallel. The point is now to deduce their true spatial orientation. Of great help is the fact that we find the projected rotation axes of the two components to be coincident. This is indicated by the velocity field of the stellar component and by the very reasonable assumption that the projected rotation axis of the disk lies along its minor axis (unfortunately we mapped the gas velocity field only at two position angles). There are consequently two possibilities for the spatial orientation of the two angular momentum vectors:

1. If the line of sight is not in the plane defined by the two vectors, they must be intrinsically antiparallel, otherwise the projected rotation axes would not be coincident. This would represent a very new phenomenology. In this case we can deduce that the stellar component rotates around one of the two axes permitted for the gas, which are principal axes.

2. If the line of sight lies in some particular position on that plane, then the observations are consistent with an orientation of the two vectors ranging from antiparallel to the limiting case of being almost perpendicular. In fact we have to consider all the possible cases of intrinsic orientation for the stellar component since NGC 5898 is an elliptical galaxy whose rotation axis is not known *a priori* (as in the case of a disk). The angular momentum vectors of the stellar component can form at very least an angle of 30°–40° with the line of sight to be consistent with the observed value of $V_{max} = 80$ km s^{-1}. These angles imply a maximum unprojected value of $V_{max} = 150$–200 km s^{-1} which corresponds to the highest observed values in dust lane ellipticals (Bertola, Galletta, and Zeilinger 1985). Given that the angular momentum vector of the gas forms an angle of 50° with the line of sight, the limiting angle between the two vectors is 80°–90°. If this is the case, namely orthogonality of the two vectors, we are encountering the well-known case of the ellipticals with the dust lane along the minor axis. There the maximum velocity gradient of the stellar component is along the apparent major axis and that of the gas is along the minor axis (Bertola, Galletta, and Zeilinger 1985). The the case of the ring galaxy NGC 5266 (Varnas *et al.* 1987) would be the example most similar to NGC 5898. In fact if we look at NGC 5266 with the line of sight lying at a right angle to the present one, it is possible to find a direction reproducing not only projected values of the velocities very similar to those observed in NGC 5898, but also almost circular isophotes. It should be noted that the probability of looking at a galaxy in this particular way is very small, since the line of sight in the orientation sphere is confined to a very restricted area in comparison with the total area which give rise to the antiparallel case. Since we have at our disposal only one case, this possibility cannot be ruled out. However, if we also include the case of the elliptical with emission lines NGC 7097, which is very similar to our case, we could reduce greatly the probability that we see these galaxies at that very peculiar orientation.

The fact that in a number of dust lane ellipticals the angular momenta of the acquired gas and of the stars are perpendicular is due to the intrinsic triaxial structure of these systems. As is well known (Simonson 1982), only two perpendicular planes, the ones defined by the intermediate and the major or the minor axis, are allowed for the gas to settle. In the minor axis dust lane ellipticals (Bertola, Galletta, and Zeilinger 1985) for instance, the gas lies in the plane defined by the minor and intermediate axis, while the stellar component rotates about the minor axis. It is clear that with different impact parameters the gas could have settled on the major–intermediate axis plane giving rise to a major axis dust lane elliptical. In this case, and more generally in any case in which the rotation axis of the stellar component is perpendicular to the equilibrium plane of the captured gas, either parallel or antiparallel angular momenta are expected. However, while the case of parallelism does not give information on the origin of the gas, the antiparallel case provides direct evidence for the external origin of the gas. This evidence has been finally found for dust lane ellipticals in the galaxy NGC 5898 discussed in this paper. This is the missing case which reinforces the previous conclusion on the origin of the gas. It should be noted that little kinematical data is available for dust lane ellipticals and that the case of parallel momenta is represented only by IC 5063 (Bergeron, Durret, and Boksenberg 1983) whose membership to this class is, moreover, uncertain.

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