The Unusual Barred S0 Galaxy NGC 4546

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Introduction

At the beginning of May 1986, during an observing run concerning the stellar kinematics in barred S0 galaxies, we observed the SB0 NGC 4546, an almost edge-on disk system, finding the presence of a very peculiar phenomenon: within the galaxy, the gas clouds are moving with similar velocities but in opposite direction with respect to the stars. This fact, present also at different position angles, makes this galaxy a unique case of disk system with large-scale, retrograde gaseous motions with respect to the stars.

The observations of NGC 4546 are part of a larger programme of study for the structure and the kinematics of SB0's, programme started at ESO in 1984 and including at the present time spectroscopic and photometric data for four galaxies. The goals of this programme are to reach a good knowledge of the kinematical properties of disk galaxies in the presence of a bar and an appropriate analysis of the stellar orbits within the bars, considered as typical triaxial structures. As a first result, we found the existence of some peculiarities in the velocity field of the first SB0 studied, NGC 6684: an oval distortion of the stellar disk and the presence of elongated stellar orbits within the bar. They confirm the existence of an oval distortion suggested by the study of some barred disk galaxies (Kormendy, 1979, 1983) and invoked also to explain and stabilize the structure of "spindle" galaxies, a type of S0's with a luminous and extended gas disk perpendicular to its symmetry plane (Schweizer, 1983).

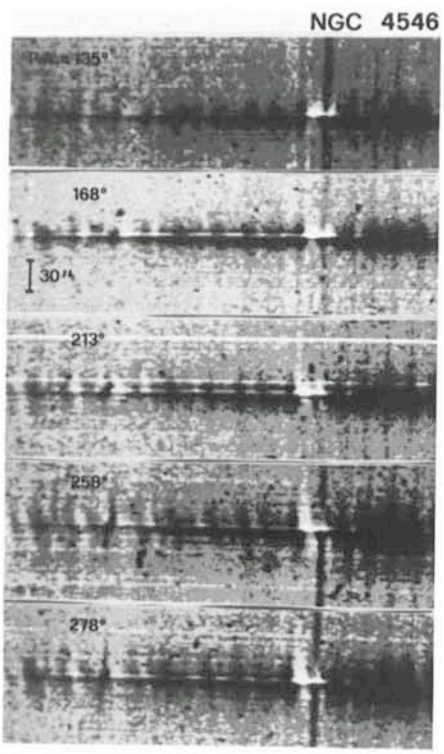

Figure 1: *Composition of the spectra of NGC 4546 at six different position angles. To make the lines more evident, the continuum has been partially subtracted in all the images. The emission lines are represented by [OIII] features (left of the spectra), with only λ 5007 clearly visible. The intense absorption lines visible in the portion of the spectra shown here are Mg I λ 5175.4, near the 5200.0 [NI] sky lines, and Ca+Fe λ 5269.0. Note that nearer to the major axis (P.A. = 258°), the emission and the absorption lines tend to be inclined because of the rotation in opposite directions. This fact characterizes the exceptionality of the kinematics of this stellar system.*

The selection of NGC 4546 as a candidate for spectroscopic and photometric studies derives from several characteristics: (i) it is quite a luminous galaxy, with B magnitude 11.3; (ii) its ellipticity is 0.52, indicating an almost edge-on system where it is possible to study the bar along one of its principal planes ; (iii) it shows the presence of the [OII] lines at λλ 3727–29 Å (Humason et al. 1956); (iv) it possesses an H I rotating disk with a velocity width for the line of 350 km/s (Bieging, 1978). All these properties make this galaxy an interesting subject of study.

Observations and Data Analysis

NGC 4546 has been studied in the nights of May 4 and 5, 1986, with the CCD and the Boller and Chivens spectrograph of the 2.2-m ESO-MPI telescope at six different position angles. The exposure times were ranging from 90^m for minor axis and intermediate angles spectra to 120^m for the major axis spectrum, at P.A. = 258° (Figure 1). The dispersion used was 1.77 Å/pixel (grating 10, second order) while the scale perpendicular to the dispersion was 1.808 arcsec pix^{-1} or about 59 arcsec mm^{-1}. The spectral interval explored was ranging from 4900 to 5700 Å. In order to study the extension of the gas and its motions outside the main galactic plane, two 60^m spectra were secured offsetting the centre of the slit by 5" on both sides of the nucleus (NW and SE, Figure 2) and perpendicularly to the major axis. An additional major axis spectrum of 15^m exposure was kindly taken for us with the same instrument by S. di

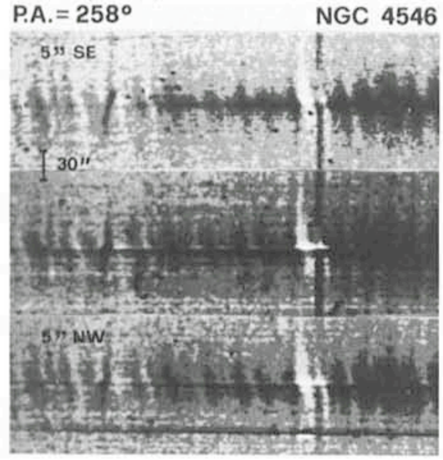

Figure 2: *The same as Figure 1, but for the spectrum of the major axis (centre) and two offset spectra at the same P.A. but at 5" (430 pc) SE and NW from the nucleus. The extension of the phenomenon of counter rotation between stars and gas appears with similar behaviour.*

Serego Alighieri on the night of May 6 at lower dispersion (5.16 Å $pixel^{-1}$, grating 16) in the interval λλ 4730–7300 Å.

In addition to these spectroscopic data, V, Hα and Gunn I frames were recorded with the CCD of the 1.5-m Danish telescope on the nights of May 6 and 7, 1986. The image of the galaxy is shown in Figure 3, from a 1^m (top) and a 15^m (bottom) V exposure. From these images, it appears that the galaxy shows a disk strongly inclined to the plane of the sky, as stated by the presence in the shorter exposure of Figure 3 of two spindles in the outer isophotes. The bar, whose presence has been mentioned by de Vaucouleurs et al. (1976), appears just like an irregularity of the isophotes roughly at 45° NE of the major axis and is completely embedded in the galaxy body. A faint absorption, probably a dust lane, appears at P.A. = 248°, ten degrees SW of the major axis. In agreement with its relative closeness, 17.8 Mpc according to the group distance (Virgo V, de Vaucouleurs, 1975), in the deeper exposure, NGC 4546 reveals in its halo the presence of a number of faint, almost stellar images, probably globular clusters. Some of them are visible in Figure 3 (bottom).

In the spectra of Figure 1, to make the lines more evident, the continuum has been partially subtracted in all the images, showing the complex texture of the spectral lines. The [OIII] emission lines are visible, but the faintest one, λ 4959, is too faint to give a measurable signal, also because of the many ab-

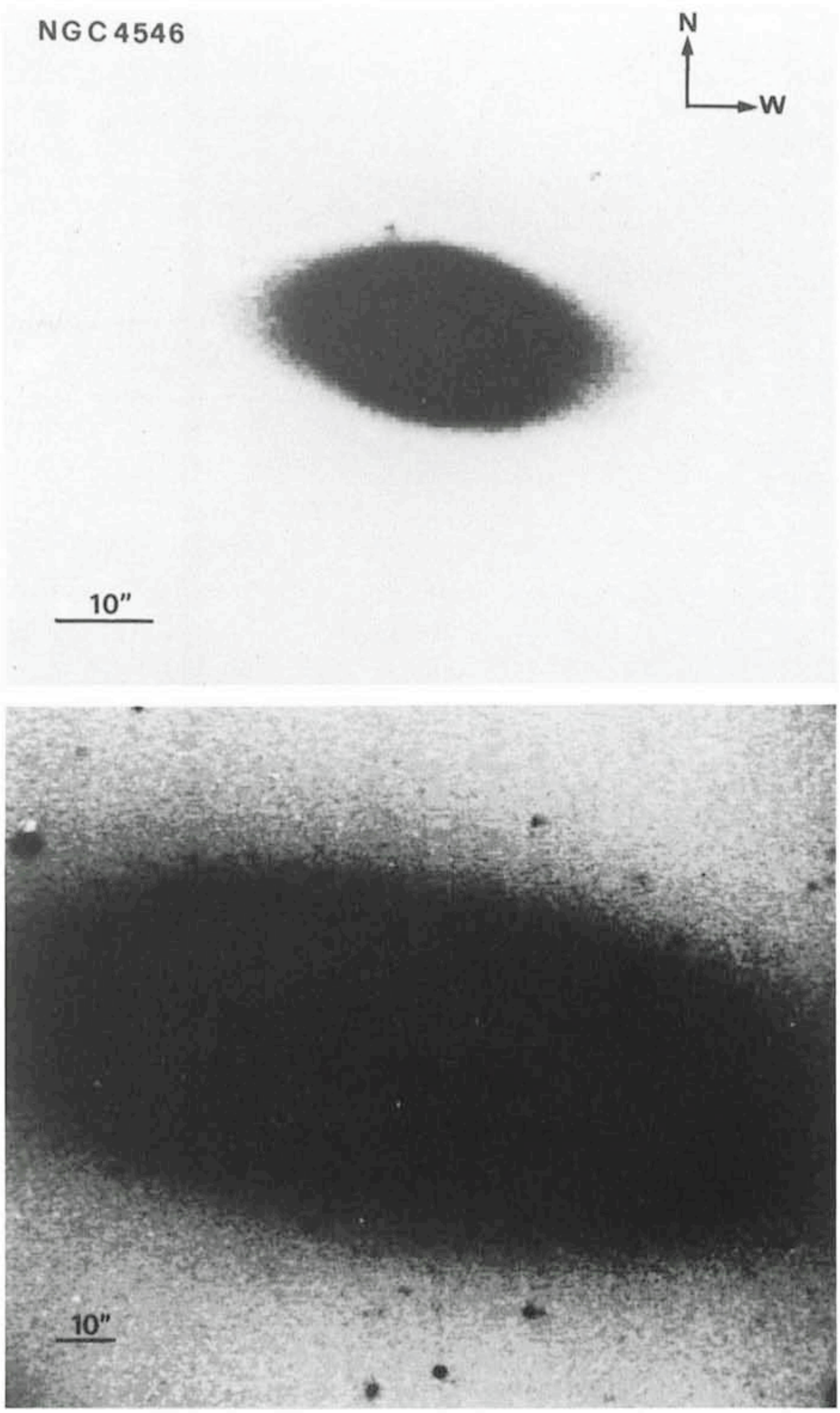

Figure 3: *Two images of the galaxy, from a 1^m (top) and a 15^m (bottom) V exposure. The bar appears just like an irregularity of the isophotes roughly at 45° NE of the major axis and is completely embedded in the galaxy body. A faint absorption, probably a dust lane, is visible ten degrees SW of the major axis. In the deeper exposure, NGC 4546 reveals in its halo the presence of a number of faint, almost stellar images, probably globular clusters.*

sorption features that are intersecting it with opposite inclination. The spectral features of MG I λ 5175.4, near the 5200.0 [N I] sky lines, Ca+Fe λ 5269.0 and Fe λ 5331.5 are visible in absorption and are the predominant lines in the spectra. From the low dispersion spectrum it is possible to see also the presence of the emission lines Hα, [N II] λλ 6548–84 and [S II] λλ 6717–31.

All the spectra were preliminarily reduced with the IHAP package at the Padova HP computer centre and analysed kinematically by interpolating Gaussian functions to the more intense emission and absorption lines. No attempt has been made to add together scan lines, in order to increase the signal-to-noise ratio. This process was repeated for each spectrum and for each scan line using a batch IHAP procedure. A sample of the results is shown in Figures 4 and 5, where the rotation curves measured from emission and absorption lines along the major axis of the galaxy are plotted. A more complete reduction of the velocity field will be performed during the next months using the technique of the Fourier Quotient which produces also the velocity dispersion of the stars.

Discussion

In most of the spectra (Figure 1), the gas lines appear inclined because of the rotation in a direction opposite to that of the stellar lines, indicating opposite directions of motion. This fact characterizes the exceptionality of the kinematics of this stellar system. In fact, at the present time, no S0 or spiral galaxy is known to possess this characteristic. The same behaviour is present in the spectra taken parallel to the major axis but with a ± 5" offset with respect to the nucleus (Figure 2). At the assumed distance of 17.8 Mpc, these offsets correspond to about ± 430 pc, showing that the phenomenon is quite extended.

A look at Figure 1 shows that along the minor axis (P.A. = 168°) the stars exhibit almost no rotation, as indicated by the lack of inclination of the absorption lines. At the same position angle, on the contrary, the gas presents residual motions that decrease until, at 135°, about along the minor axis of the bar, the emission lines tend to straighten. This fact indicates that the lines of nodes of the planes where the gas and the stars are moving are not at the same position angle. This kinematical difference is confirmed by the analysis of the velocity gradients. Their values for the stellar motions show a cosine decrease with the P.A. reaching a maximum of about 12 km s^{-1} $arcsec^{-1}$ at P.A. = 80°, very close to the major axis of the galaxy, in agreement with the expectation for circular orbits on the galactic plane. Peculiar orbits appear in the inner part of the system. The study of the gas rises more complex problems: in fact, along the major axis, when the slit crosses the bar, a dip of the rotation curves towards lower velocity is visible. This characteristic disappears in the offset spectrum at 5" SE, indicating gas flow or elongated orbits within the bar. The same behaviour is presented by the analysis of the velocity gradients of emission lines, which follow an approximate cosine law with line of the nodes at 225° (near the bar major axis) and a

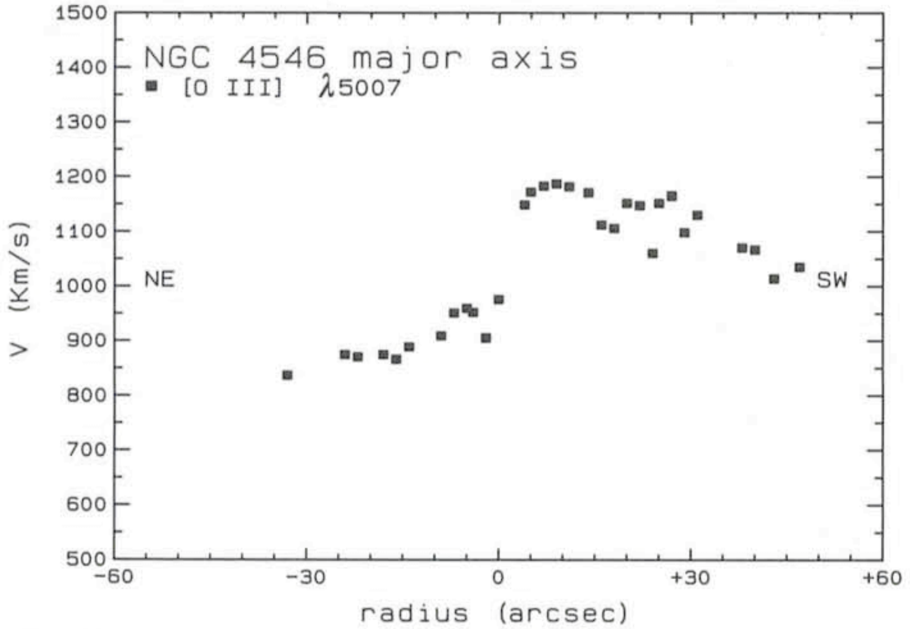

Figure 4: *Rotation curve for the gas along the major axis, from a Gaussian interpolation of the spectral line [OIII] λ 5007.*

maximum of 12.5 km s^{-1} $arcsec^{-1}$ gradient, with the exception of the rotation curve measured at P.A. = 213°, whose inner slope of about 5 km s^{-1} $arcsec^{-1}$ is well down the expected value off 15 km s^{-1} $arcsec^{-1}$.

Then, if all these motions are evolving along a plane, the plane of the gas is not coplanar with that of the stars and the gas existing within the galaxy shows a radial flow along the bar which could explain the asymmetries observed. In addition, since the maximum extension of the gas is observed near the major axis, about 30° from its direction of maximum velocity gradient, the gas itself appears confined within a more or less asymmetric disk, of projected dimension 1.7 × 8.2 kpc, not aligned with the stellar disk of the galaxy neither with the bar.

Where did this gas come from? One possible hypothesis is that the gas is circulating in one of the retrograde families of orbits possible in triaxial systems (de Zeeuw and Merrit 1983) or the bars (Freeman 1966, Contopoulos and Papayannopoulos 1980). It is expected in this case that, since the gas clouds are moving together with the stars in a narrow tube, this prevents their collapse by collision or dynamical friction. But this phenomenon involves confined regions of space, contrary to that observed. The same problem is present for a second possibility: that we are observing gas confined in a retrograde portion of a "hot" velocity field, similar to that found for some globular clusters in our galactic halo (Oort 1965). With the exception of the two above-mentioned cases, we find it difficult to imagine a mechanism that discriminates between gas and stars with common origin, driving it in two opposite directions of rotation. A third and alternative hypothesis is that the gas has not the same origin as the stars but is the result of a more or less recent acquisition, and comes from a retrograde collision with a dust cloud or a gas-rich dwarf galaxy. The discovery of hot stars or HI bridges with other close stellar systems would give an interesting check of this hypothesis.

Concluding this short note, we would like to draw the attention to another case of counter-rotation known in the literature, although the nature of this system is quite different from the disk galaxy considered here: along the major axis of the galaxy NGC 7097, classified E4, Caldwell et al. (1986) have measured a gas rotation of 200 km/s superimposed on a slow stellar rotation of a few tens of km/s in opposite direction.

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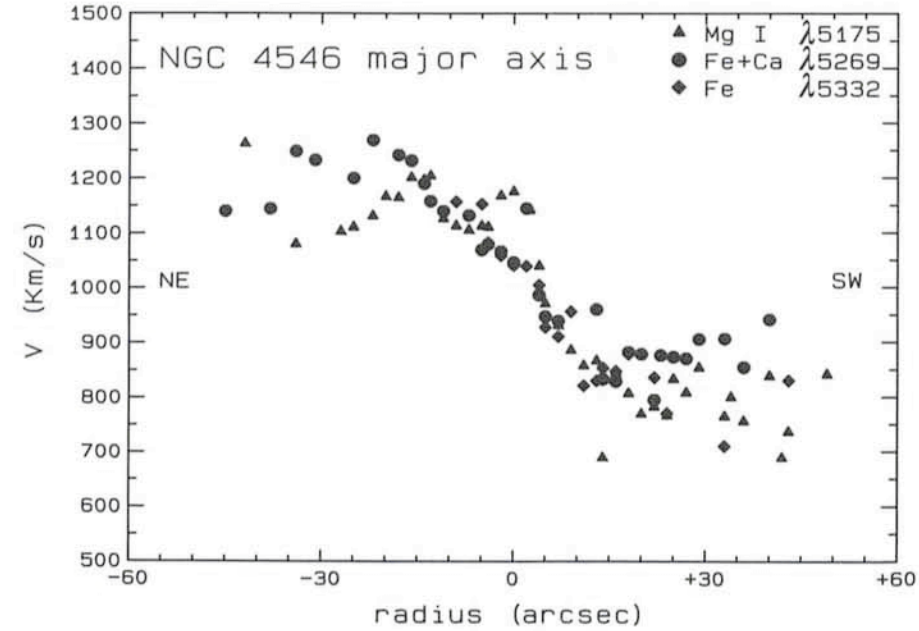

Figure 5: *The same as Figure 4, but for the stars. The stellar lines used are labelled with different symbols.*