The H I kinematics of a Thick Boxy Bulge Galaxy: NGC 1055

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Abstract

We present 21-cm H I observations of the edge-on Sa/Sab galaxy NGC 1055 obtained with the VLA. The gas distribution is rather symmetric, as is the kinematics. However, this symmetry is broken at one side of the galaxy, and also an anomalous surface density distribution is present on the opposite side. The overall scenario of NGC 1055 may find a reasonable explanation in a soft merger with a dense satellite onto the disk, in which the accreted material enriches the bulge. This hypothesis could explain the peculiar H I kinematics and the boxy/peanut isophotal distortions seen in the optical morphology. An attempt of analysis has been made, separating the regularly rotating from the anomalous gas through a decomposition of profiles into Gaussian components.

1 Introduction

In recent years the term "minor merger" has been adopted to describe a merging process between a primary galaxy and a small satellite with a mass ratio of 0.1 or less. Although minor mergers are a much more common phenomenon than mergers between galaxies of comparable mass, the observational signatures of the former are weaker and less spectacular.

Shells, bridges and ripples are signs of accretion events, but also the formation (and subsequent dissolution) of a bar within an otherwise stable disk is a consequence of an interaction. In several papers it has been proposed to explain the formation of the boxy/peanut (b/p) shaped bulges in spiral galaxies through the bar buckling mechanism. Although a bar is difficult to observe in edge-on galaxies, where the b/p bulge is easily seen, several bar-diagnostics are nowadays available (plateau in the light profile, de Carvalho & da Costa 1987; double-peak in the position-velocity diagram, Kuijken & Merrifield 1995; N-body simulation and modeling, Combes et al. 1990, Athanassoula 1992), and a relation between bars and b/p bulges is suggested. Another promising scenario to explain the formation of the b/p isophotal distortions is through the accretion of material into a spiral host galaxy. Several authors (Binney & Petrou 1985; Rowley 1986) have proposed a whole range of possible scenarios from the slow accretion of one or more small satellite galaxies to the merger of two galaxies of similar size. All these scenarios of accretion were supported by numerical simulations.

The b/p bulges are not so peculiar as it seemed in the past. In fact, an investigation of a complete sample of 1350 edge-on galaxies derived from the Third Reference Catalogue of Bright Galaxies (RC3, de Vaucouleurs et al. 1991) reveals that 45% of all bulges are b/p shaped (Lütticke et al. 2000). A new class of bulges named Thick Boxy Bulges (TBBs) were observed in this sample. These unusual bulges present the characteristics of being thick, box-shaped and prominent compared to the size of the disk. New observations that we collected so far indicate peculiarities and asymmetries in these galaxies, some possessing possible merger remnants and merging satellites, without any evidence for bars. The predicted scaling relation between bar-size and b/p structure which results from numerical simulations does not hold for the TBBs (Lütticke et al. 2000). As a conclusive picture we argue in favor of the smallest accretion events as a process of the formation of a bar, leading to b/p shaped bulges, while larger accretion events (soft merger with companions) are the origin of the TBBs.

The main goal of this work is to test the hypothesis of a soft merger as a possible reason for the thickness and boxiness of these bulges. The cannibalism of small galaxies by larger systems may explain box-shaped galaxies (Binney & Petrou 1985, Whitmore & Bell 1988), in particular the thickness and the prominence of the bulge with respect to the disk (Aguerri et al. 2001).

NGC 1055 was investigated as part of the project to study the formation and evolution of thick bulges, in order to obtain information about the overall kinematics of TBBs galaxies. It is a nearby edge-on galaxy classified as SBb in the RC3, and as Sa/Sab by Shaw (1993). Together with NGC 1068 it forms a binary system, which is part of a small group (NGC 936, NGC 1084, and NGC 1087). NGC 1055 is the first galaxy in this sample for which we have collected the H I data, and for which we report first evidence for the accretion hypothesis.

2 Observations

The H I observations were performed in July 1997 with the VLA in the C-array. Using the 4ABCD spectral line mode, the field was simultaneously observed in two partially overlapping spectral bands. The calibration and continuum subtraction were done using the Astronomical Image Processing System (AIPS)[1]. The visibilities were examined with the program TVFLG, where the *UV* data of poor quality were flagged. The primary flux calibrator was 0137+331 (3C48). The phase, gain and bandpass were calibrated with observations of 0238+166 every 10 minutes before and after each target scan. We used the task UVLSF for the continuum subtraction by fitting a linear baseline to a selected group of channels. The emission-free channels taken at the edges of the band (13 in total) were selected by visual inspection. The *UV* data were then transformed to the XY plane and cleaned using the program IMAGR. The images presented here were extracted from a cube obtained by a robust weighting. The primary beam correction has been applied on the 0th moment maps using the task PBCOR. Further data processing was carried out with the GIPSY image processing system (van der Hulst et al. 1992), taking advantage also from the Karma visualization package[2]. As a first approach the moment analysis was used, and in a second iteration a decomposition of profiles into two Gaussian components was performed with GAUFIT. Using GAUSSCUBE two separate cubes of H I data were constructed, based on the parameters of the two Gaussians that resulted in the fit. Using these cubes, a new analysis was performed.

2.1 Distribution and Kinematics of the Neutral Hydrogen

The integrated H I flux profile shows the double-peaked characteristics of spirals, without an apparent trend of lopsidedness. We estimate a total H I mass of 4.9×10^9 $M_\odot$, using a distance of 13.05 Mpc ($H_\circ = 75\,\mathrm{km\ s^{-1}\ Mpc^{-1}}$, $1'$ corresponds to 3.79 kpc). Figure 1 shows the large extent of the neutral gas compared to the optical image. The total extent of the H I is at least 37 kpc, which corresponds to 1.4 times the de Vaucouleurs radius ($R_{25} = 14$ kpc). The main body of the H I distribution is oriented approximately along the position angle of the major axis of the galaxy

[1]AIPS is distributed by the National Radio Astronomy Observatory.

[2]Gooch, R.E., 1995, "Space and the Spaceball", in Astronomical Data Analysis Software and Systems IV, ASP Conf. Series vol. 77, ed. R.A. Shaw, H.E. Payne, & J.J.E. Hayes, ASP, San Francisco, p.144-147.

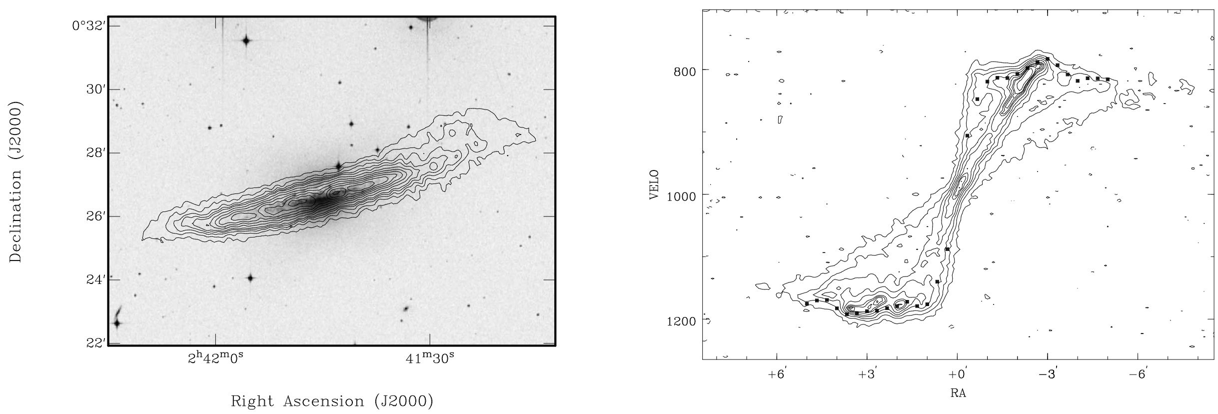

Figure 1: The total H I intensity map of NGC 1055 overlaid on the DSS image (grey scale) reveals a regular gas disk inside the optical body and disturbed contours at the edges. The contours range from 0.2 to 3.3 $\times$ 10^{21} atoms cm^{-2} in steps of 3.7 $\times$ 10^{20} atoms cm^{-2} (*left*). Position-velocity diagram obtained from a slice in P.A. = 103°, where the filled squares show the rotation curve. The diagram appears to have an asymmetric shape, with a higher column density and a bump at lower velocities. The contours are -1.7, 1.7 (2σ) to 32 mJy beam^{-1} in steps of 3.4 mJy beam^{-1} (*right*).

(P.A. = 103°), and is coincident with the dust lane. The total intensity map reveals a regular gas disk inside the optical body. On the northwestern side the H I distribution appears asymmetric, and in the south a smooth trend of bending pulls the contours out and up. The peak of the diffuse material in the NW - which seems quite unsettled - is weak, and lacks any obvious optical counterpart.

Overall, the distribution of the velocities is quite symmetric. However, disturbed contours are visible on both outer halves of the velocity field at the extreme velocities. There are perturbations especially on the NW side, and in the central region an indication of two components can be noted. The main peculiar features observable in the individual channel maps are in the range between 813 and 860 km s^{-1}, and between 1176 to 1155 km s^{-1}. In the receding range of velocities a separate blob of the emission is seen at 15 kpc from the centre, with a gap just past the end of the undisturbed stellar disk. This peculiar emission, inclined by some degrees against the major plane of the H I distribution, may be responsible for the soft bending at the SE edge in the total intensity map. On the approaching side, spread-out emission is seen at the NW edge at velocities around 850 km s^{-1}. The H I flux density of this asymmetric northwestern side has a value of 2.14 Jy, which implies a mass of 4.45×10^{8} $M_{\odot}$.

In the position-velocity diagram (PVD), taken along a P.A. of 103°, H I is detected out to 5′ from the centre, and even further on the southeastern side (Fig. 1). The PVD appears to have an asymmetric shape, with a higher density and a bump at lower velocities. The observed asymmetries between the two halves are also visible above and below the plane. In a sequence of slices separated by 15″ parallel to the major axis, the H I may be traced up to 1.′5 above the plane, while below the emission disappears at 45″.

The velocity dispersion of NGC 1055 shows very high values, which is entirely due to beam smearing. With a peak value of 6 $M_{\odot}$ pc^{-2}, typical for Sab/Sb galaxies (Roberts & Haynes 1994), the radially averaged H I surface density does not show the typical exponential drop-off beyond the optical region, but a regular and soft decrease with radius.

3 Discussion

The present observations suggest a scenario for NGC 1055, where asymmetries are seen in the distribution as well as in the kinematics of the neutral hydrogen. The asymmetric H I emission, especially in the outermost northwestern region, seems to be an unrelaxed structure produced by external effects due to tidal interaction or merging.

The peculiar H I distribution in NGC 1055 could be the result of a gravitational interaction with another galaxy of the group, like NGC 1068. This interaction might have produced a strong warp, visible at the edges where the gravitational force is weaker. However, the shape of the warp is rather unusual. In fact, the outer H I disk does not bend away from the central plane as is usual for warped galaxies (i.e. forming a point-symmetric "integral sign"), but rather bends in the same direction (i.e. forming a mirror symmetry with respect to the minor axis). Moreover, no clear signs of a change in the line of nodes are noticed in the rotation curve. It is not clear whether a warp could explain the separate blob of emission visible at 15 kpc from the centre at approaching velocities.

The kinematics might be induced by a soft merger with a companion, where the reason why the non-detection of the optical counterpart it may be the destruction of the companion itself during the encounter. The mass contained in the separate blob of emission might be consistent with a gas-rich dwarf satellite.

The overall scenario of NGC 1055 may find a reasonable explanation in a soft merger of a dense satellite onto the disk, in which the accreted material enriches the bulge. This hypothesis could explain the peculiar H I kinematics and the b/p isophotal distortions seen in the optical morphology.

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